NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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# HELIOCENTRIC ABORT ΔV REQUIREMENTS FOR 1977 THROUGH 1986 MARS CONJUNCTION-CLASS MISSIONS



Advanced Mission Design Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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By John T. McNeely and Ellis W. Henry
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# HELIOCENTRIC ABORT ΔV REQUIREMENTS FOR 1977 THROUGH 1986

# MARS CONJUNCTION-CLASS MISSIONS

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## SUMMARY

The purpose of this report is to present a parametric analysis of heliocentric abort trajectories for Mars conjunction-class missions from 1977 through 1986. The parameters of variation are return-to-Earth flight time and time-of-abort initiation after trans-Mars injection. Return-to-Earth flight times of up to 400 days were investigated, and it was found that for the first 3 to 5 months of the nominal trans-Mars flight, trajectories with 5-month to 1-year return times are available with abort ΔV requirements of less than 13 000 fps. A reference spacecraft design is discussed, and it is determined that the vehicle has approximately 13 000 fps available for abort if both the Mars orbital insertion and the trans-Earth injection propulsion stages are used. The Earth-entry velocity for these abort trajectories is less than 40 000 fps, although entry velocities of up to 44 000 fps are considered. Of those missions discussed (1977 through 1986), the 1977 mission has the highest heliocentric abort ΔV requirements, and the 1983 mission has the lowest.

A matched-conic model was used to compute all of the Earth-to-Mars trajectories, and a patched-conic model was used to compute all of the abort trajectories. A brief discussion of both techniques, as well as some interesting problems which were encountered, are included in this report.

## INTRODUCTION

Several nominal mission profiles and a spacecraft with the capability to perform a Mars orbital and landing mission were defined in the reference. In the "Abort and Alternate Missions" section of that report, a brief discussion was presented of the phase termed early return from heliocentric space; this document is an expansion of that section. The early return phase was so termed because the nominal Earth-to-Mars trajectory is altered by a thrusting maneuver to enable a direct return

to Earth. For this report, the early return maneuver will be defined as an abort. The resultant trajectories have return-to-Earth flight times of 5 to 12 months. These times are considerably shorter than the time required for either the nominal mission or a flyby alternate mission, both of which require approximately 30 months. In this report, the abort capabilities of a specific spacecraft are determined and are related to the heliocentric space abort trajectories for Mars conjunction-class missions from 1977 through 1986.

## REFERENCE SPACECRAFT DESIGN

The significance of the abort velocity requirements for any mission can be interpreted only when viewed in conjunction with a specific vehicle design. The vehicle used for this report was obtained from the reference and is described in this section. A schematic of the vehicle is shown in figure 1, and a weight summary is given in table I. The spacecraft systems are designed for a lifetime of at least 1000 days. The Mars orbit insertion (MOI) and trans-Earth injection (TEI) propulsion stages weigh 242 000 pounds, and the total spacecraft weight is 451 700 pounds. For a heliocentric abort maneuver, the manned landing module, the Martian moon rendezvous module, and the probes can be staged, which reduces the total spacecraft weight to 338 200 pounds, and thus increases the spacecraft $\Delta V$ capability. If it is assumed that both the MOI and TEI propulsion stages are available for use and have a specific impulse of 400 seconds, then the spacecraft has a $\Delta V$ capability of 13 000 fps. If only the MOI stage is available, the $\Delta V$ capability would be 6885 fps. If only the TEI stage is available, the $\Delta V$ capability would be 6115 fps.

## REFERENCE TRANS-MARS TRAJECTORY

Mars conjunction-class missions were discussed extensively in the reference to the extent that the minimum-energy trajectories (near-Hohmann transfers) were determined for both the Earth-to-Mars and the Mars-to-Earth portions of the mission. A schematic of the heliocentric phase of a typical Mars conjunction-class mission is shown in figure 2. The relative positions of the planets at times of departure and arrival as well as the outbound and inbound trajectories are indicated in figure 2. A 50-day launch window was constructed around each of the minimum energy Earth-to-Mars trajectories. Characteristics are given in table II which correspond to the first day of each launch window for these trajectories to Mars between 1977 and 1986. The characteristics include launch dates, Earth-to-Mars flight times, and $\Delta V$'s required to attain the trajectories

after departure from a 262-n. mi. orbit around the Earth. The 1986 mission has the shortest trans-Mars flight time and the lowest trans-Mars injection (TMI) $\Delta V$ (200 days and 11 538 fps). The 1981 mission has the highest TMI $\Delta V$ (12 992 fps), and the 1977 mission requires the longest trans-Mars flight time (360 days). For this report, the five trans-Mars trajectories summarized in table II are the nominal trajectories from which aborts are initiated.

## COMPUTATION TECHNIQUES AND TRAJECTORY PROGRAM MODELS

The nominal missions discussed previously will now be considered generally; the Earth-to-Mars portion of these missions will be referred to collectively as the reference trajectory. The basic function of the computer program used was to compute the spacecraft position and velocity vectors along the reference trajectory as a function of time after TMI, and, from that point, to compute the velocity required (and hence $\Delta V$) for a direct return to Earth as a function of return time. A schematic of the abort situation which shows a typical abort trajectory is presented in figure 3. The dashed line represents the reference trans-Mars trajectory, and the orbits of Mars and the Earth are as indicated.

The $\Delta V$ required for abort is principally a function of two variables: time after TMI until abort initiation and time allowed for return to earth. Thus, a complete study of the $\Delta V$ problem requires a variation of both these quantities throughout the range of interest. The computer program was designed to fix the value of the first time variable and to compute $\Delta V$'s that would correspond to discrete values of the second variable. Then the first time variable was incremented, and the process was repeated. The results, which were plotted by the computer (dd80 process), are included in this paper and will be discussed in a later section.

The trajectory program permits a choice from three degrees of complexity: a matched-conic model, a patched-conic model, and a massless planet model, all of which compute three-dimensional trajectories. The matched-conic model has the predominant characteristic that it exhibits no discontinuity in either position or velocity at the sphere of influence (SOI) of a planet. The patched-conic model is similiar in that it exhibits no discontinuity in the velocity vector; however it does allow a discontinuity in position. This discontinuity has no appreciable effect on the velocity required to intercept a point or on conditions considerably removed from a planet's SOI. The massless planet model, as the name implies, does not consider the gravitational attraction of any of the planets; thus, no sphere of influence is associated with the departure or target planets.

The matched-conic model is used to compute the Earth-to-Mars trajectory and points along that trajectory to initiate a direct return to Earth. This model was chosen because some of the abort points, namely those associated with the shortest times after TMI, are still relatively near the Earth SOI, and it is not desirable to start the abort computation near a discontinuity in position. For the abort trajectory, the return-to-Earth flight times are 80 days and greater; and, although the abort point can be relatively near the Earth SOI, the SOI will not be entered for a rather large number of days. In fact, for many of the return trajectories, the spacecraft will increase its distance from Earth during the early portion of the return flight. The patched-conic model is used for this phase because it is simpler and computationally faster and does not compromise the results.

Use of the massless planet model (the simplest and fastest model) for either or both portions would compromise only some of the results, specifically, aborts initiated early in the trans-Mars flight. However, exactly which missions and the degree of compromise could not be easily ascertained except by comparison. Consequently, this model was not used except for the preliminary investigation.

Some seemingly paradoxical conditions were encountered, as well as some unexpected situations, and these items are noted for future similar studies. Although all the abort trajectories began outside the Earth SOI and the spacecraft spent a considerable portion of the return flight outside the sphere, it was noted that after entering the SOI the spacecraft had less than escape velocity (i.e., the spacecraft was in an elliptical orbit). The paradox was suggested by the following question: how can a spacecraft near a planet with only elliptical speed (or energy) escape the planet's SOI; or, conversely, how can a spacecraft come from outside and enter an elliptical orbit? At first, this phenomenon seems contradictory to matched- or patched-conic theory because it is assumed that hyperbolic speed is required to escape the SOI of a planet, after which the gravitational attraction of that planet can be ignored. However, this is not true. For example, because the radius of the SOI has some finite value, an elliptical orbit with an apoapsis radius of somewhat greater value than the radius of the SOI (still finite) can be defined. Thus, a spacecraft can escape an SOI from an elliptical orbit, and it need not be stated whether or not the planet has been escaped for this to be true. Then an SOI can also be entered with an entry velocity less than that of a free fall from infinity.

Numerically, a free fall from infinity to the Earth sphere of influence (500 000 n. mi.) is approximately 3044 fps. Thus, if the velocity relative to Earth immediately inside the SOI is less than 3044 fps, the orbit is elliptical.

Finally, to apply this discussion to the immediate problem, when the spacecraft reaches the Earth SOI from a heliocentric trajectory, vector algebra is applied, and the heliocentric velocity of the earth is subtracted from the heliocentric velocity of the spacecraft to find the velocity of the spacecraft relative to the planet. When the magnitude of this vector is less than 3044 fps, the spacecraft enters an elliptical orbit.

This detailed discussion has been presented because most interplanetary conic programs assume that the trajectory inside an SOI must be hyperbolic; that is, the programs include only hyperbolic equations and employ V-infinity equations, asymptotes, or asymptotic matching at the sphere. Such programs are not equipped to handle elliptical entries; indeed, such conditions cannot occur for trajectories between the several innermost planets (though the massive planets Jupiter and Saturn may be exceptions). However, this condition did arise frequently for the abort problem in this report.

## RESULTS AND DISCUSSION

The data presented in the figures of this report are separable into two distinct parts: figure 4 and figures 5 through 9. The data presented in figure 4 are essentially selections from the remaining figures and reflect a mission analysis with regard to the more desirable abort profiles, particularly those profiles with minimum $\Delta V$'s and low earth entry velocities. A more comprehensive range of parametric variations without regard to selection criteria are shown in figures 5 through 9.

The impulsive $\Delta V$ requirements for a direct return to earth after aborts from the 1977 through 1986 Mars missions are presented in figure 4. The $\Delta V$ requirements are given as a function of the time of abort initiation after TMI. The data points correspond for the most part to local minimum values of $\Delta V$, subject to a maximum allowable entry velocity, for that particular abort initiation time. The corresponding return-to-Earth flight time is so indicated. For example, if an abort should be initiated 20 days after the 1977 TMI, a large range of return flight times are available [fig. 5(d)]. The return flight time that corresponds to the lowest possible abort $\Delta V$ of 10 476 fps is 290 days and is plotted in figure 4(a). The Earth entry velocity is 36 265 fps. Return times of more or less than 290 days are available at a slightly more expensive $\Delta V$ cost and for a decreased or increased Earth entry velocity. Obviously, this tradeoff should be considered. In figure 4, trajectories with Earth entry velocities of up to 40 000 fps, 41 000 fps, and 44 000 fps are represented as indicated by the figure key. If the allowable entry velocity is increased, the time after TMI is increased for which abort is possible for a given $\Delta V$ cost.

For the 1977 Mars mission [fig. 4(a)], the abort $\Delta V$ requirement is less than 13 000 fps for the first 90 days after TMI; the minimum value is 10 400 fps. These values are for an Earth entry velocity of less than or equal to 40 000 fps. An entry velocity consideration of 44 000 fps increases the time limit to 114 days. During the first 30 to 40 days of the nominal flight, reasonable abort $\Delta V$'s are encountered for return flight times of 150 to 180 days. Later portions of the nominal flight require return times of approximately 1 year to obtain reasonable $\Delta V$'s. The general trends discussed here are essentially the same for all of the nominal missions except that the $\Delta V$ requirements decrease and the times after TMI for possible aborts increase as the 1983 mission is approached. Specifically, the abort $\Delta V$ requirement is less than 13 000 fps for the first 108 days of the 1979 mission, for the first 133 days of the 1981 mission, and for the first 152 days of the 1983 mission if the entry velocity is less than or equal to 40 000 fps. The minimum $\Delta V$ is 9180 fps for the 1979 mission, 7760 fps for the 1981 mission, and 6730 fps for the 1983 mission. The 1986 mission is slightly different in that trajectories with 6-month return times and reasonable $\Delta V$'s are possible for only the first few days of the mission. The minimum $\Delta V$ is 8060 fps, and the $\Delta V$ is below 13 000 fps for the first 85 days. For an entry velocity of 44 000 fps, the $\Delta V$ is below 13 000 fps for the first 121 days.

As discussed in the reference spacecraft design section of this report, the vehicle has a $\Delta V$ capability of 13 000 fps if both MOI and TEI propulsion stages are available with a specific impulse of 400 seconds. With this much $\Delta V$ capability, abort is possible during the first 85 days of all the missions and for as long as 152 days during some missions. If either the MOI or the TEI propulsion stage is totally disabled, abort cannot be successfully accomplished.

The abort $\Delta V$ requirements and the corresponding earth entry velocities for a wider range of return trajectories are presented in figures 5 through 9. For the range of flight times considered, near 180° transfers (which usually result in high inclination return trajectories and high $\Delta V$ cost) were encountered and correspond to the upturned discontinuities shown in some of the figures. In other cases, the absence of data is characterized by trajectories with earth entry inclinations which exceed approximately 70°. These data were arbitrarily omitted because the associated trajectories would probably be operationally undesirable. Figures 5 through 9 are included because of their validity independent of the criteria of figure 4 and because they can show certain trends which influence selection by other than absolute rules. In addition, these figures show the parameters for trajectories other than those selected and presented in figure 4.

## CONCLUSIONS

Heliocentric abort trajectories from Mars conjunction-class missions (1977 through 1986) are possible during the first 3 to 5 months after TMI with Earth entry velocities of less than 40 000 fps and with $\Delta V$ requirements of less than 13 000 fps. Return-to-Earth flight times vary from 5 months to 1 year. Both the MOI and the TEI propulsion stages of the reference spacecraft are required to satisfy abort $\Delta V$ requirements. If either stage is not operational, the abort mode is switched to a Mars flyby with total missions times of up to 3 years. The heliocentric abort $\Delta V$ requirements are highest during the 1977 mission and lowest during the 1983 mission.

TABLE I.- REFERENCE SPACECRAFT WEIGHTS

| | |
|---|---|
| Manned landing module, lb | 91 700 |
| Manned landing module dry (crew of 4), lb | 35 000 |
| Manned landing module expendables (1300 days), lb | 26 000 |
| Meteoroid protection, lb | 5 740 |
| Earth entry module, lb | 15 100 |
| Onboard experiments, lb | 6 360 |
| Probes, lb | 10 300 |
| Martian moon rendezvous module (MMRM), lb | 11 500 |
| Installation for MMRM and probes, lb | 5 000 |
| Gravity tube, lb | 3 000 |
| TEI fuel ($I_{sp}$ = 400 sec), lb | 67 300 |
| TEI stage dry, lb | 14 700 |
| MOI fuel ($I_{sp}$ = 400 sec), lb | 140 000 |
| MOI stage dry, lb | 20 000 |
| Total | 451 700 |

TABLE II.- NOMINAL EARTH-TO-MARS TRAJECTORIES

FOR MISSIONS BETWEEN 1977 and 1986[a]

| Mission year | Launch date, J. D. | Flight time, day | ΔV TMI, fps[b] |
|---|---|---|---|
| 1977 | 2 443 400.0 | 360.0 | 12 643 |
| 1979 | 2 444 150.0 | 340.0 | 12 643 |
| 1981 | 2 444 900.0 | 320.0 | 12 992 |
| 1983 | 2 445 670.0 | 280.0 | 12 820 |
| 1986 | 2 446 555.0 | 200.0 | 11 538 |

[a]These are conjunction-class trajectories taken from the reference.

[b]Trans-Mars injection (TMI) departure is from a 262-n. mi. circular orbit around the Earth.

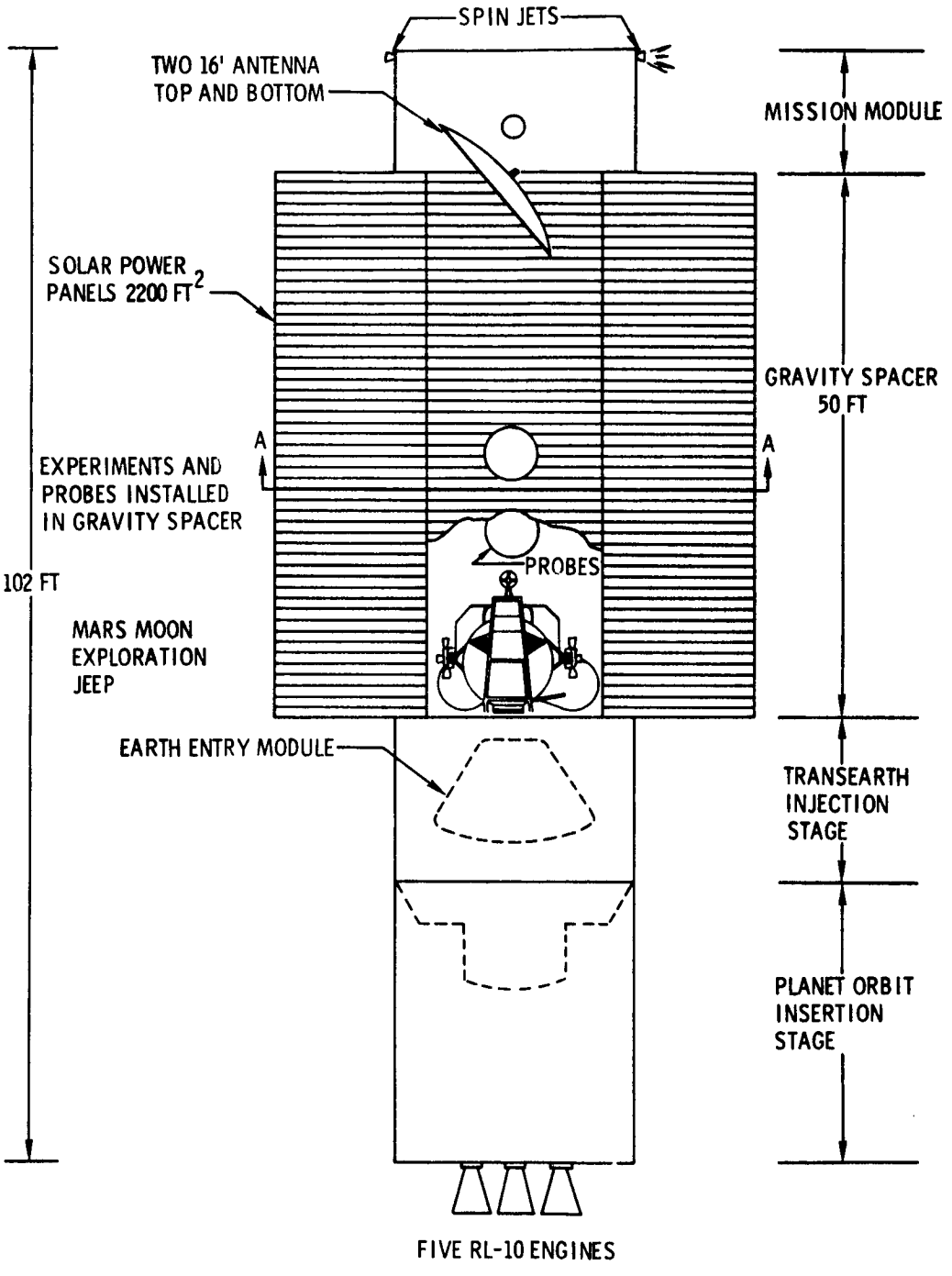



Figure 1.- Reference spacecraft design.

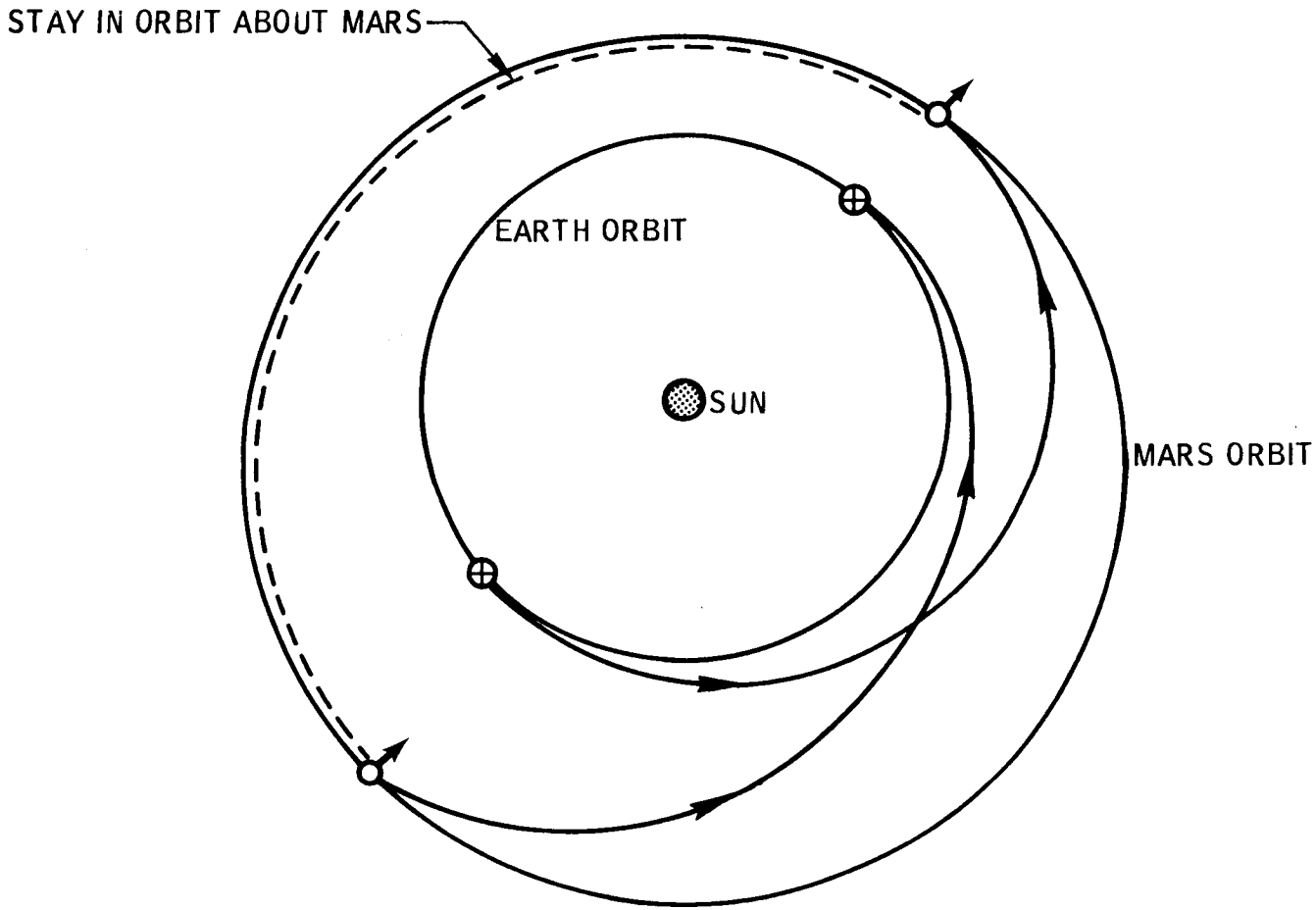



Figure 2.- Heliocentric phase of nominal Mars landing mission.

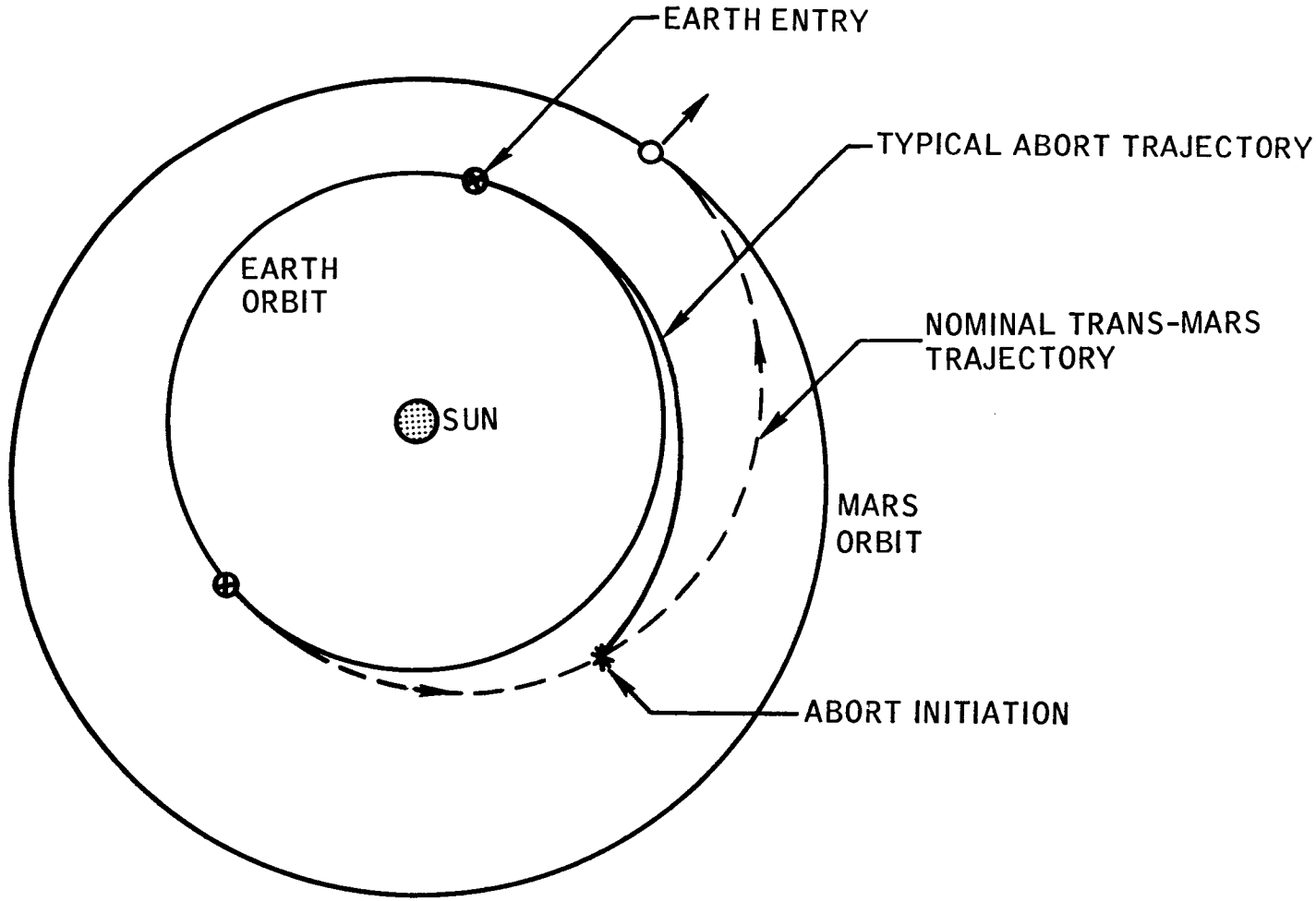
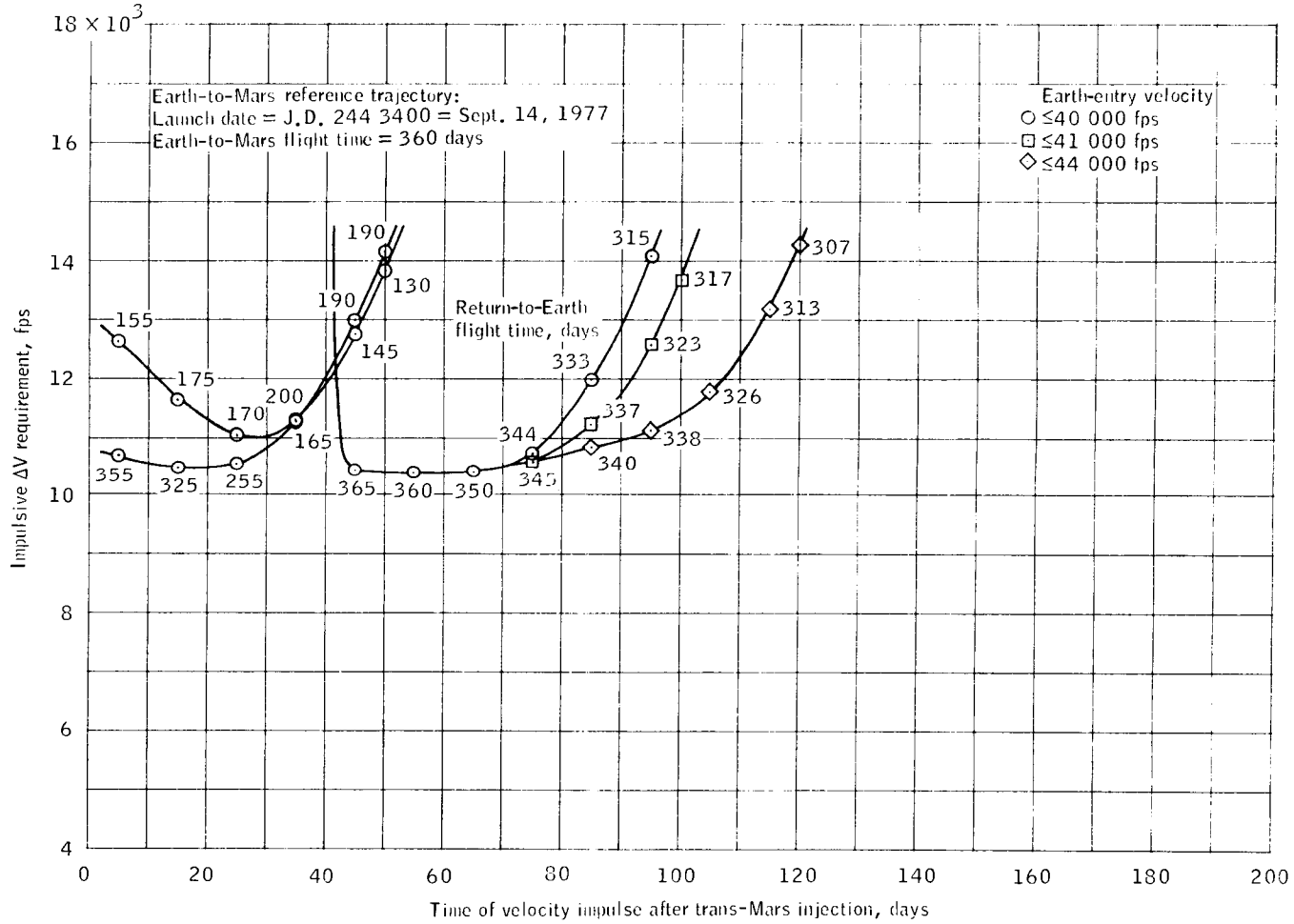
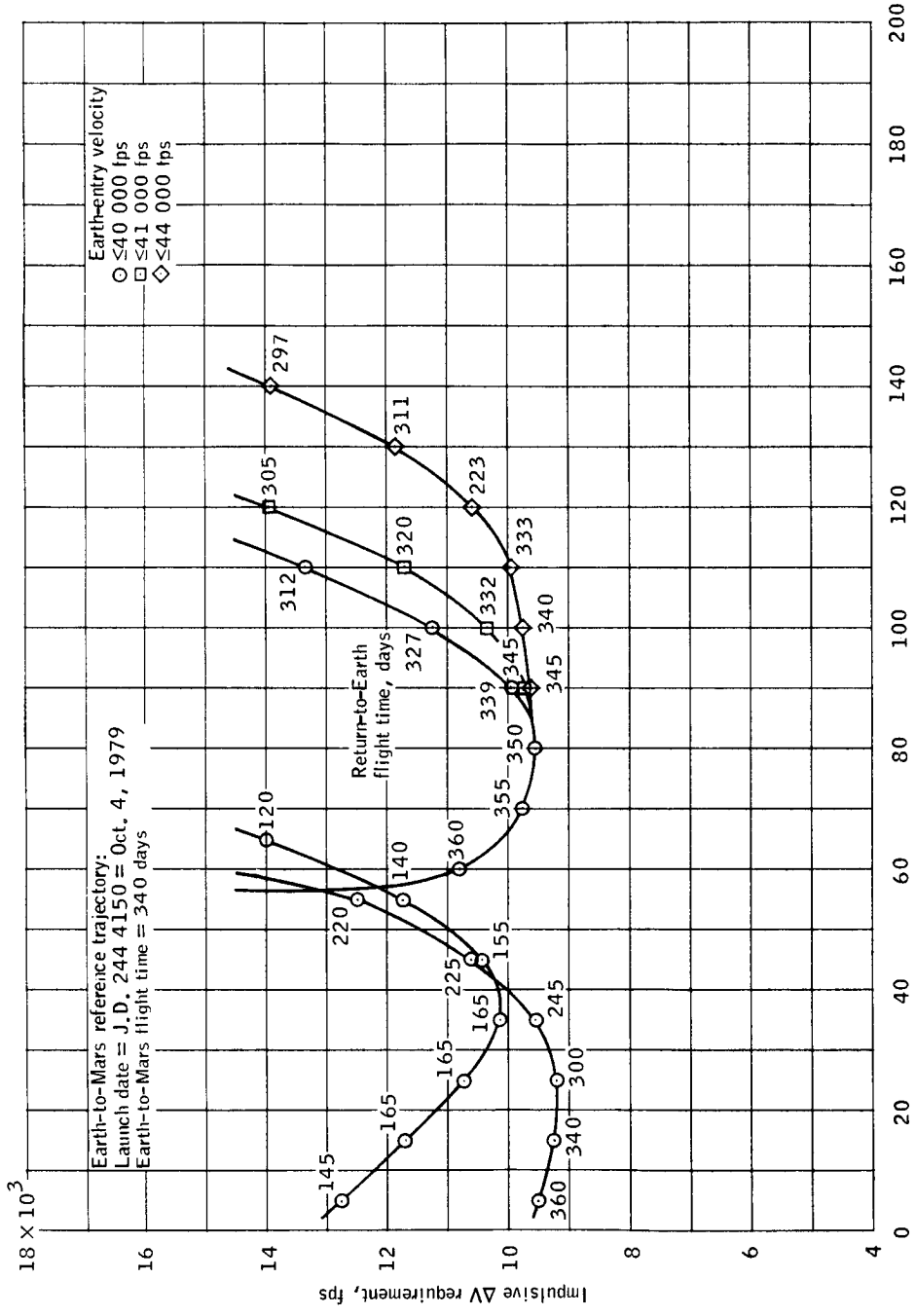



Figure 3.- Typical abort profile.



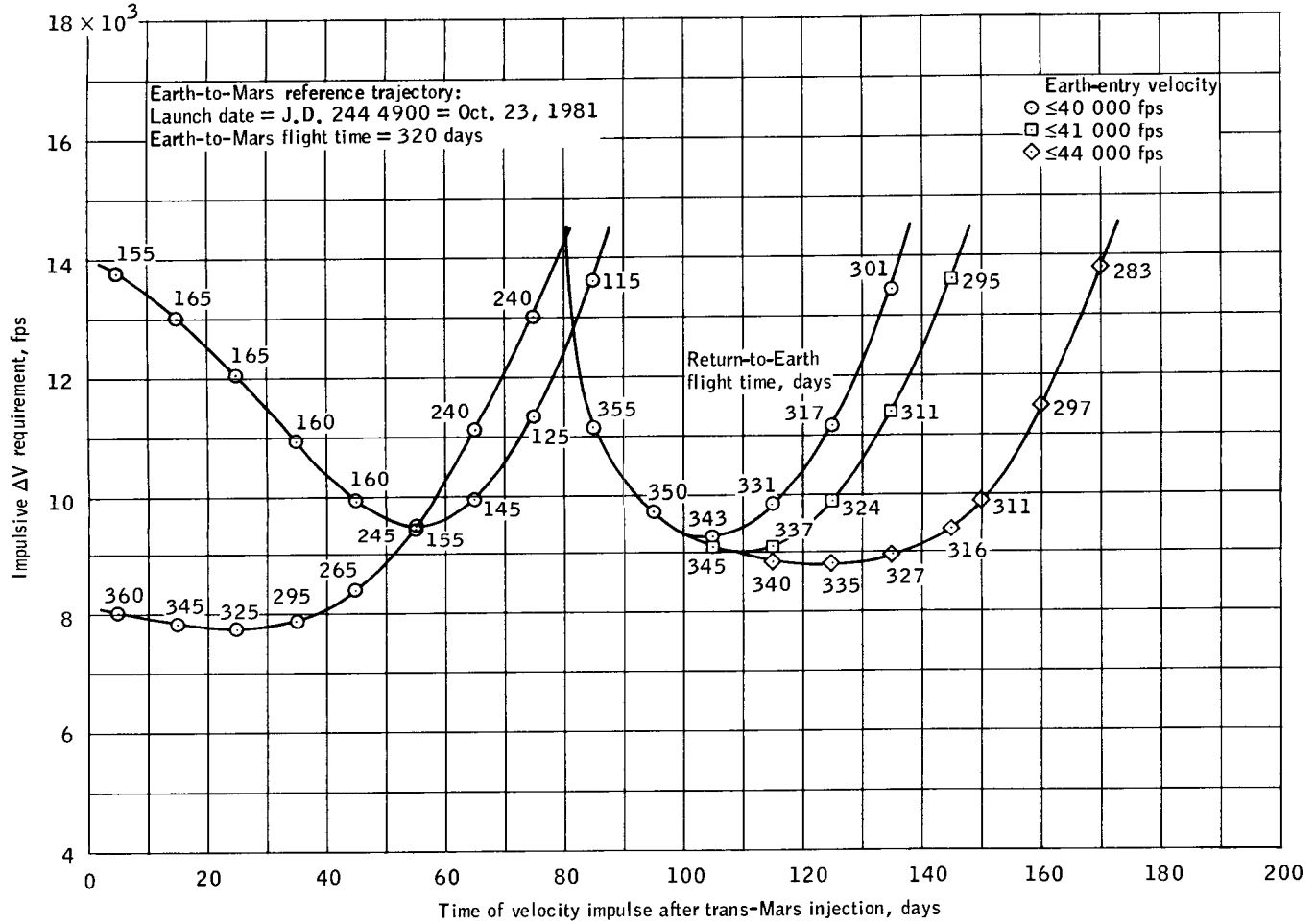

(a) 1977 Mars conjunction class mission.

Figure 4.- Heliocentric abort ΔV requirements for trans-Mars trajectories.



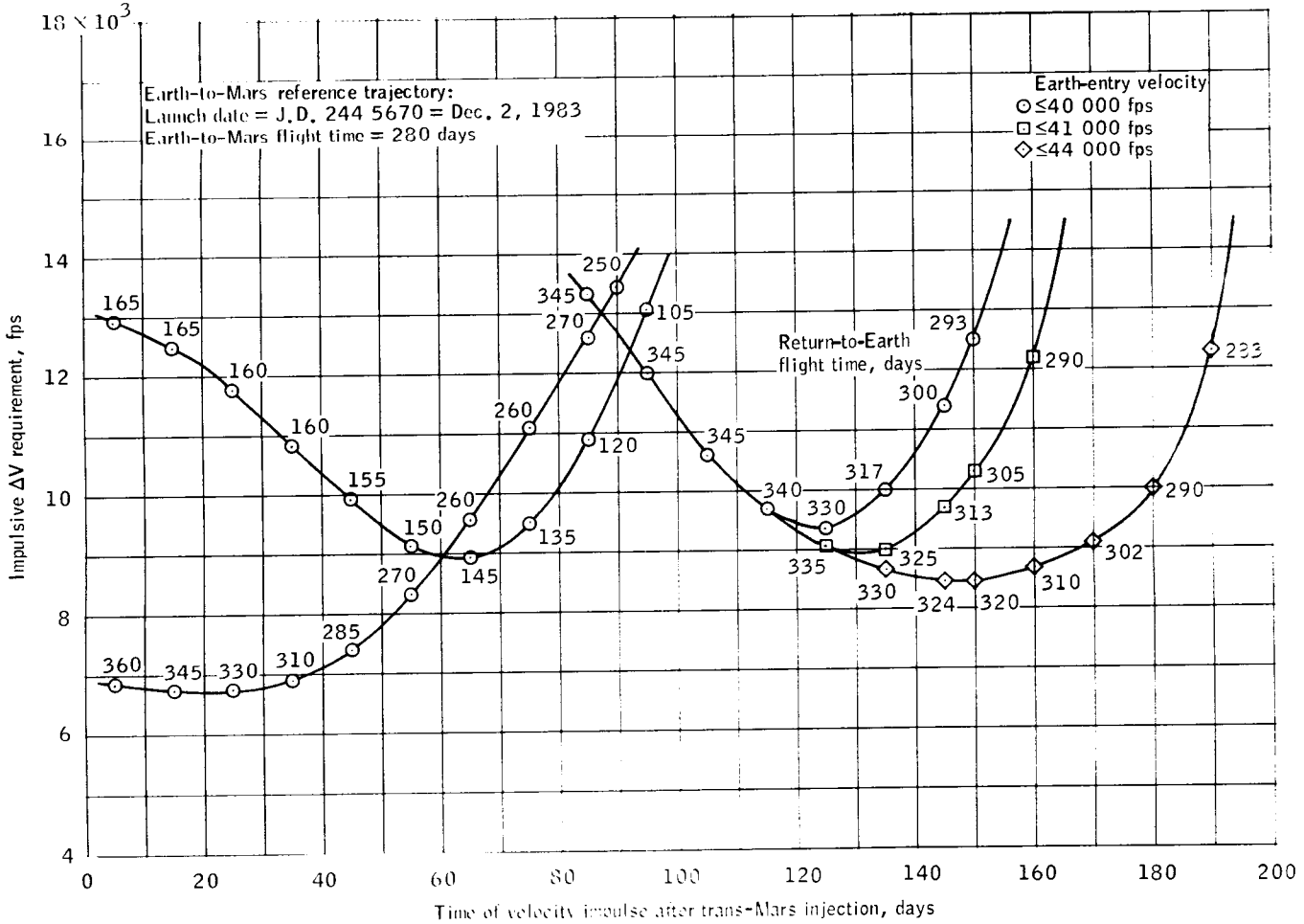

(b) 1979 Mars conjunction class mission.

Figure 4. - Continued.



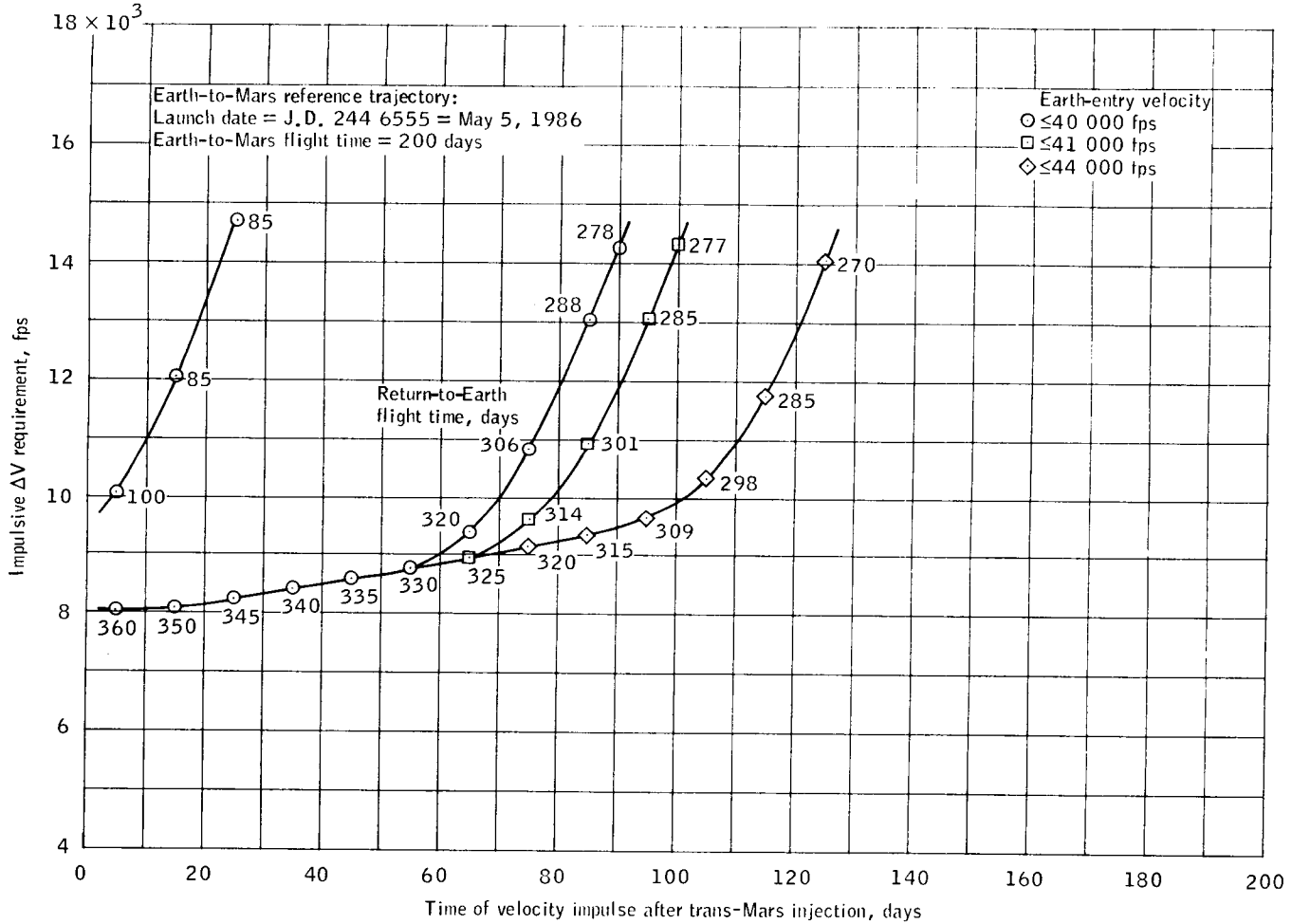

(c) 1981 Mars conjunction class mission.

Figure 4.- Continued.



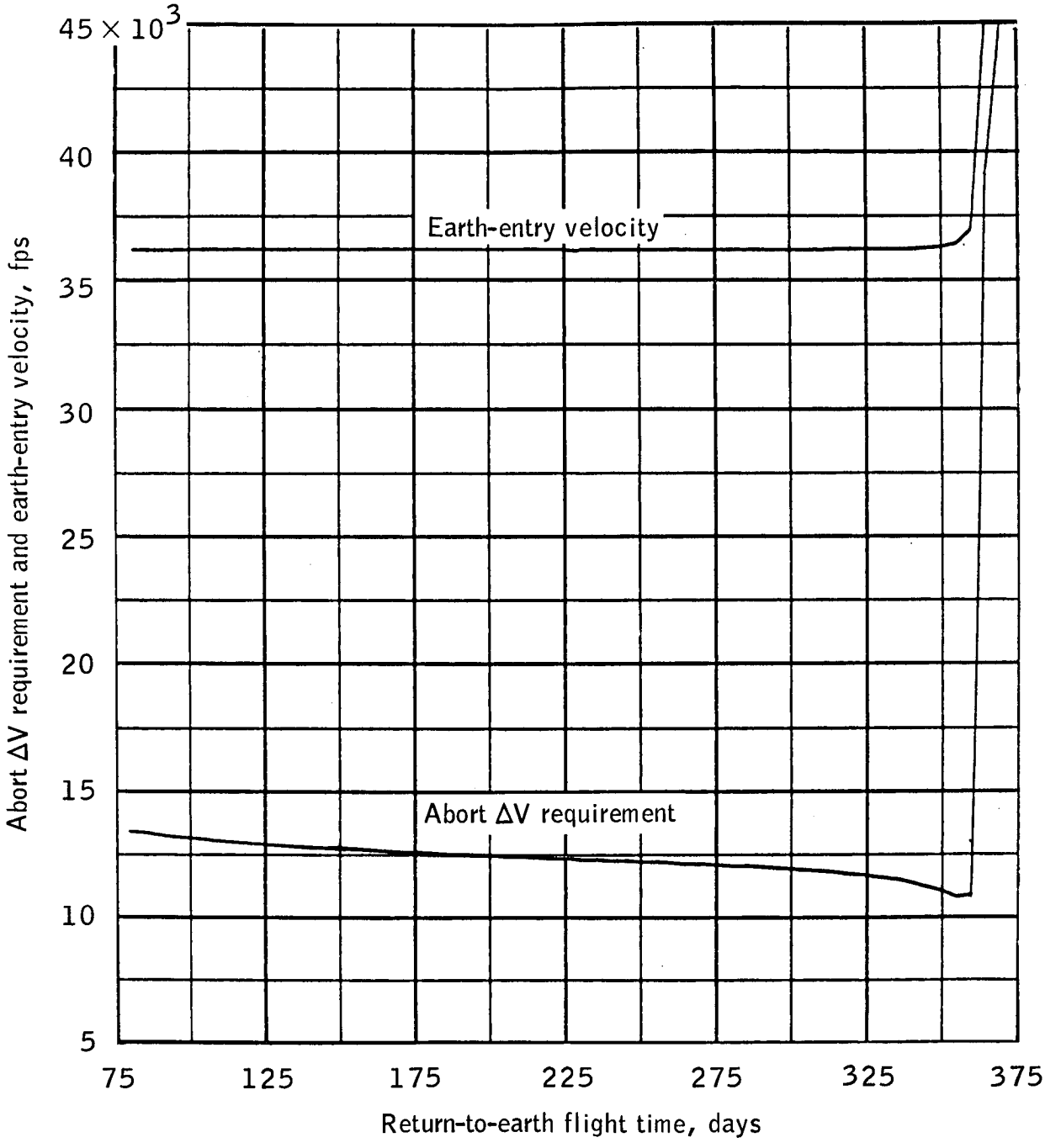

(d) 1983 Mars conjunction class mission.

Figure 4.- Continued.



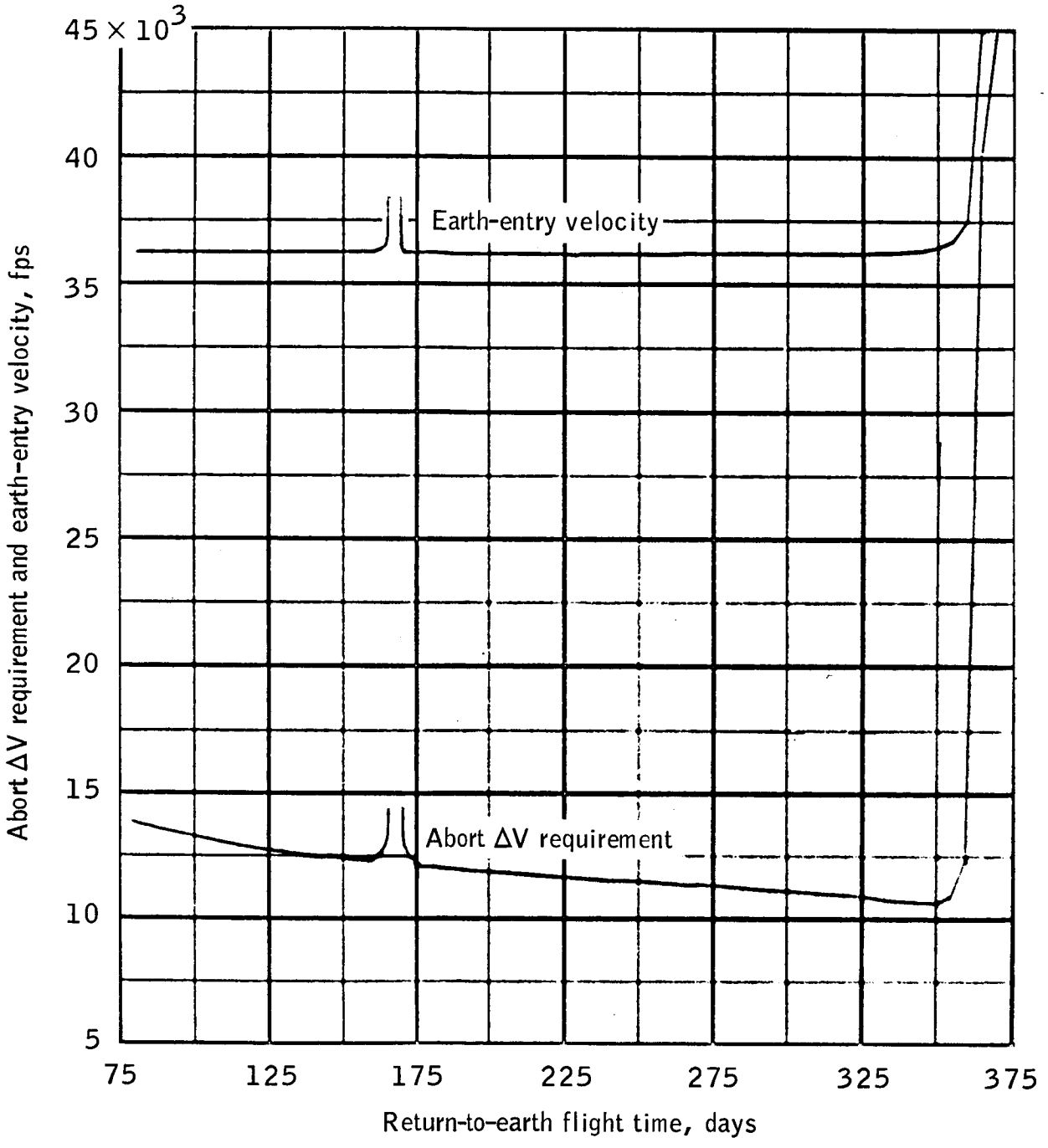

(e) 1986 Mars conjunction class mission.

Figure 4.- Concluded.



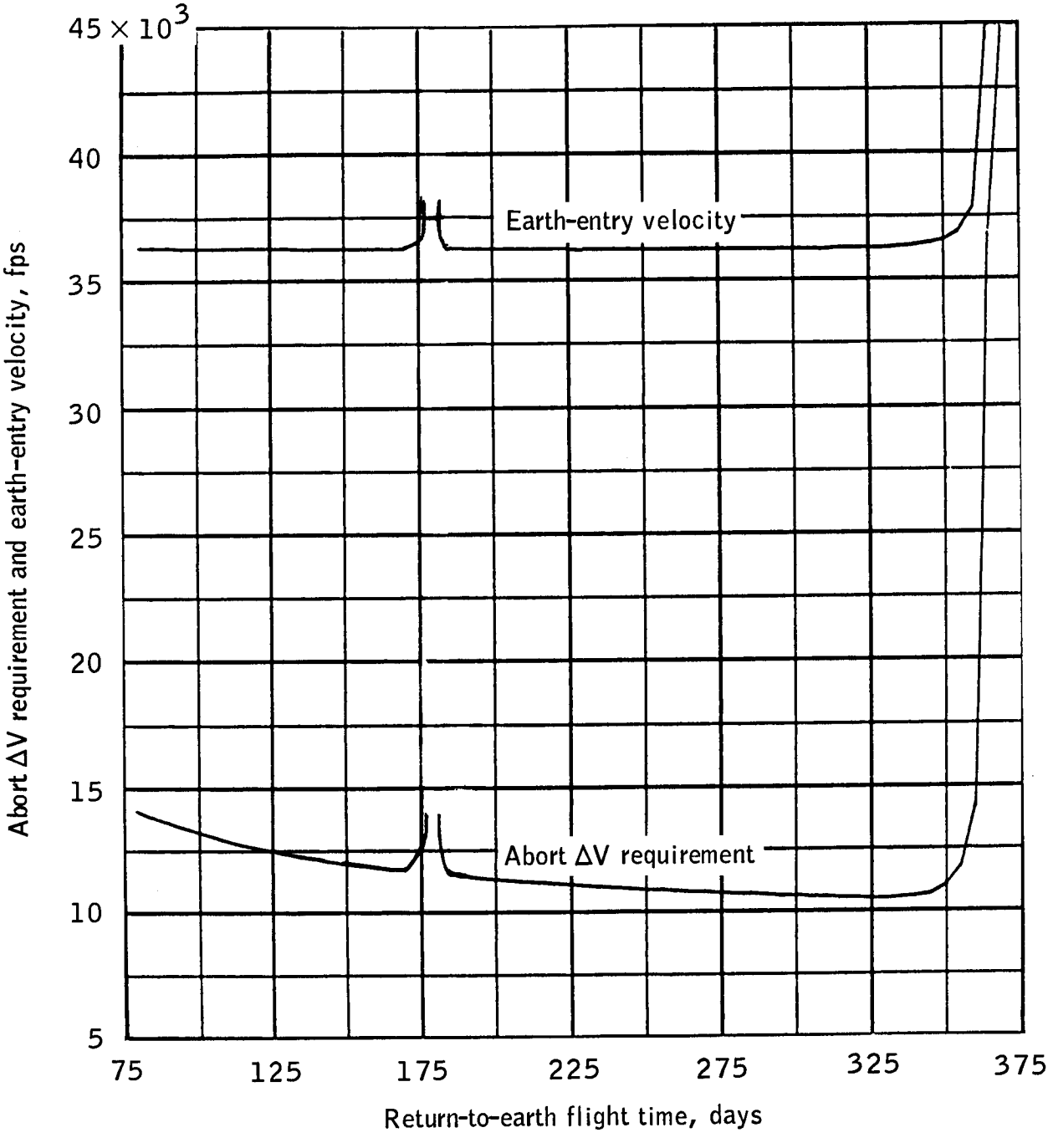

(a) Elapsed time to abort is 5 days after TMI.

Figure 5.- Velocity characteristics of heliocentric abort trajectories, 1977 Mars conjunction class mission.



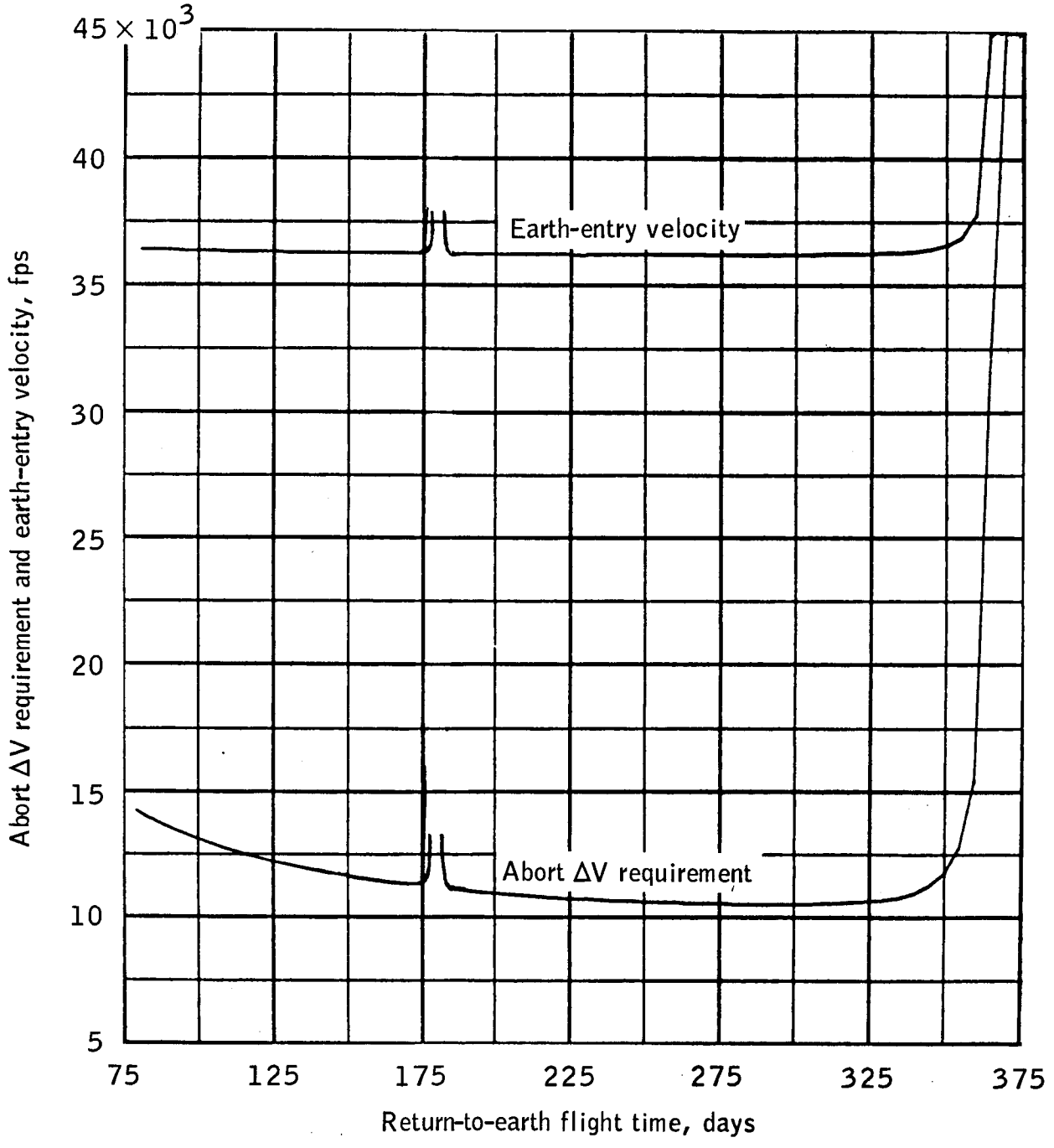

(b) Elapsed time to abort is 10 days after TMI.

Figure 5.- Continued.



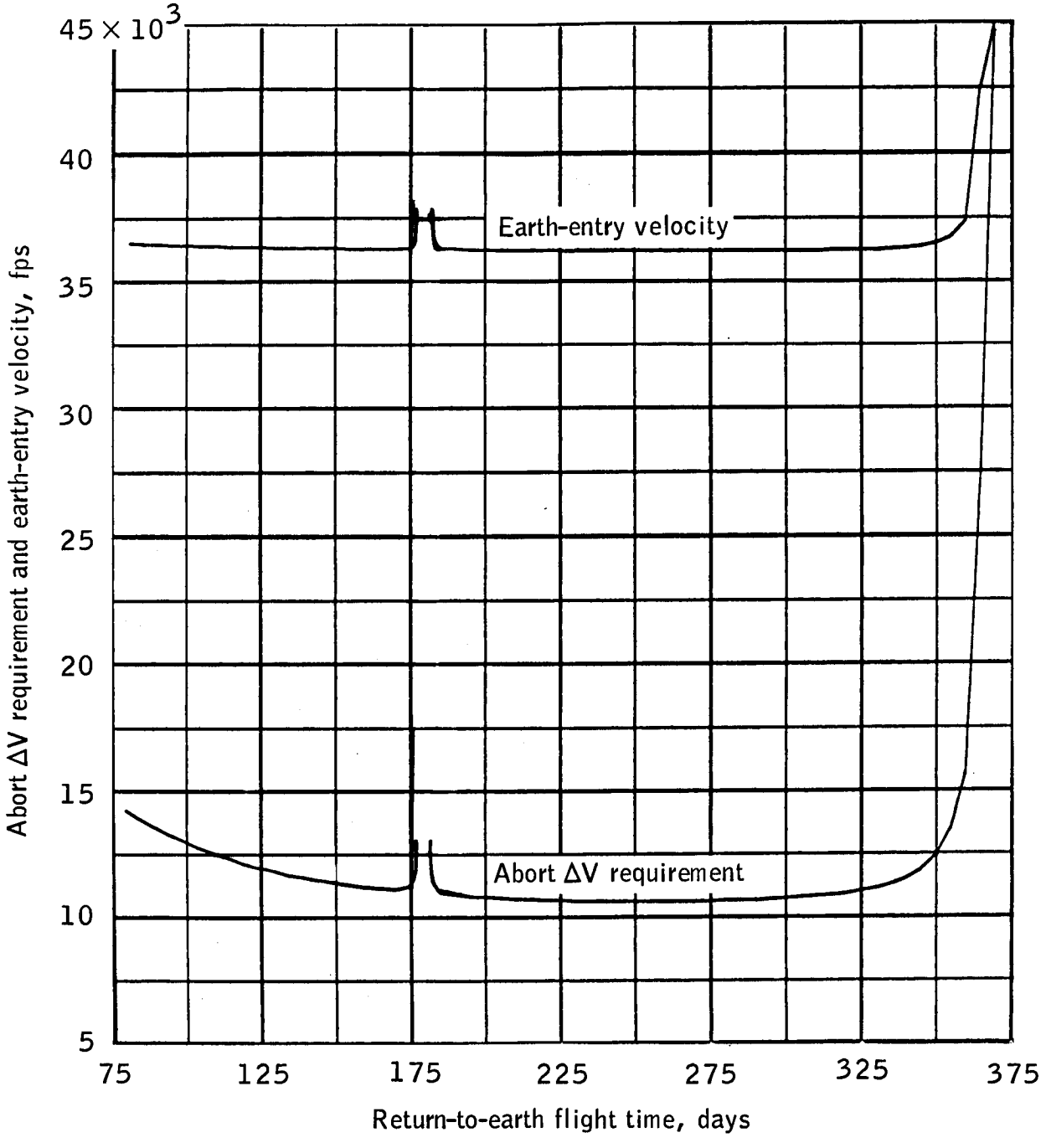

(c) Elapsed time to abort is 15 days after TMI.

Figure 5.- Continued.



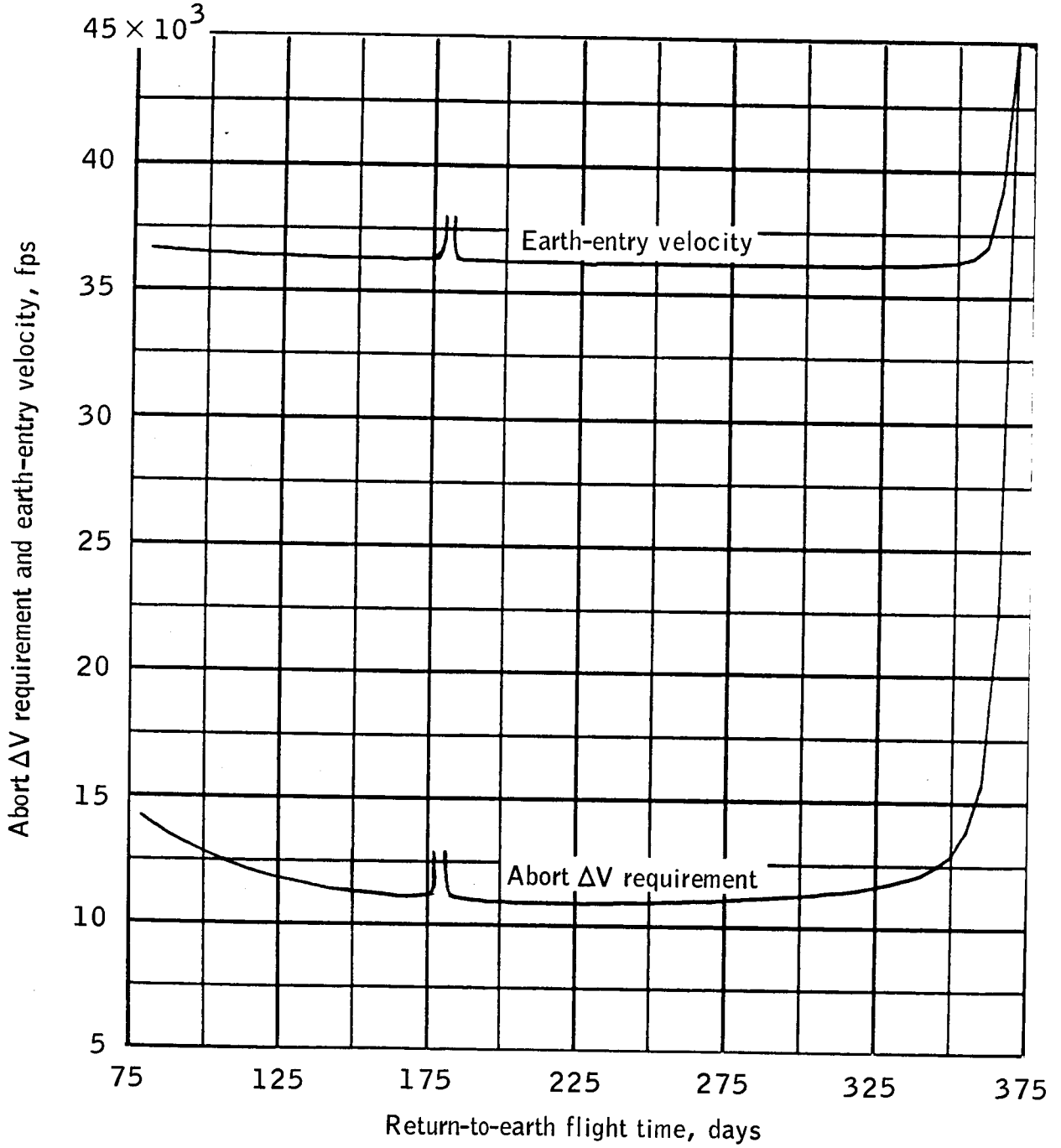

(d) Elapsed time to abort is 20 days after TMI.

Figure 5.- Continued.



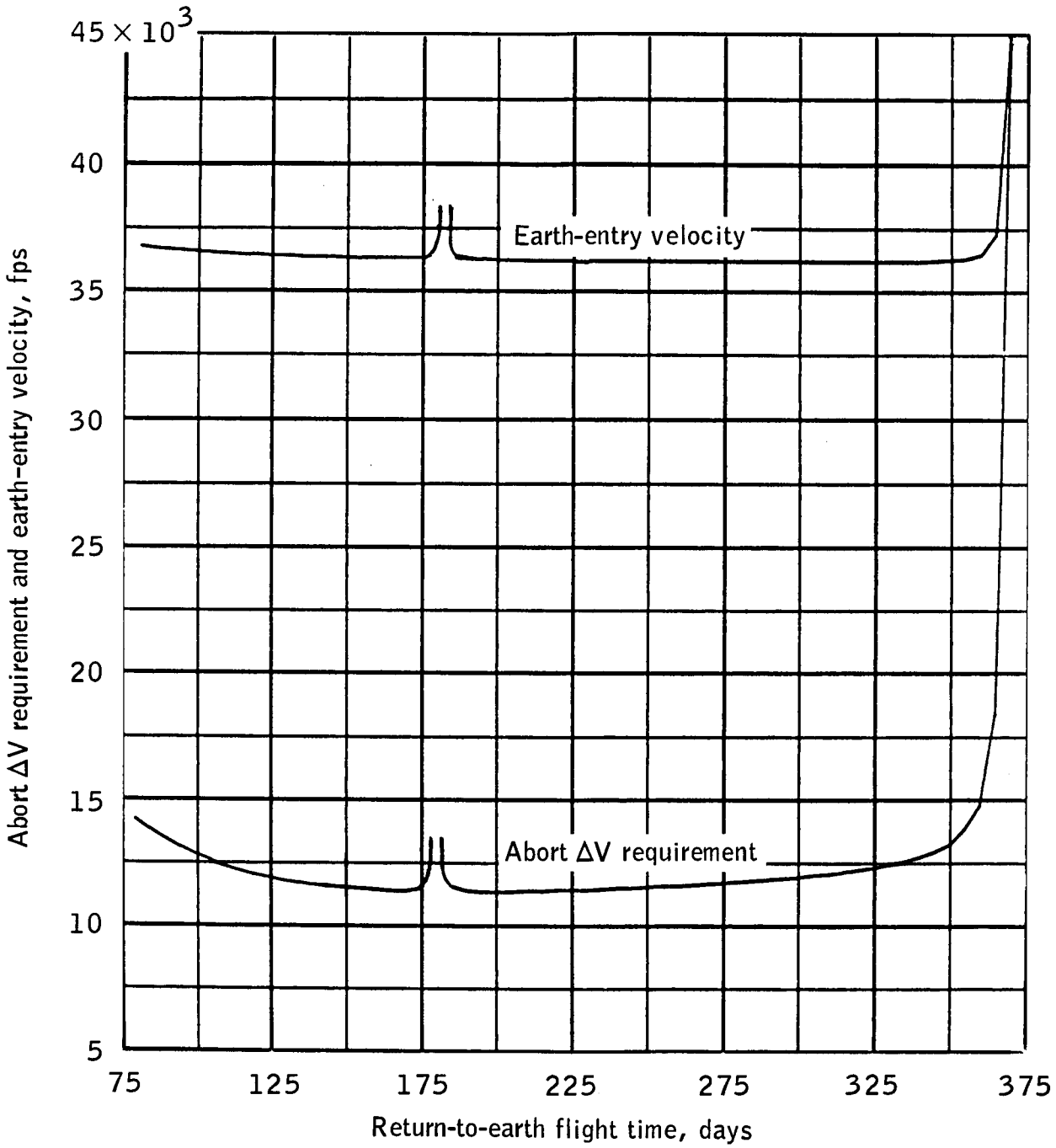

(e) Elapsed time to abort is 25 days after TMI.

Figure 5.- Continued.



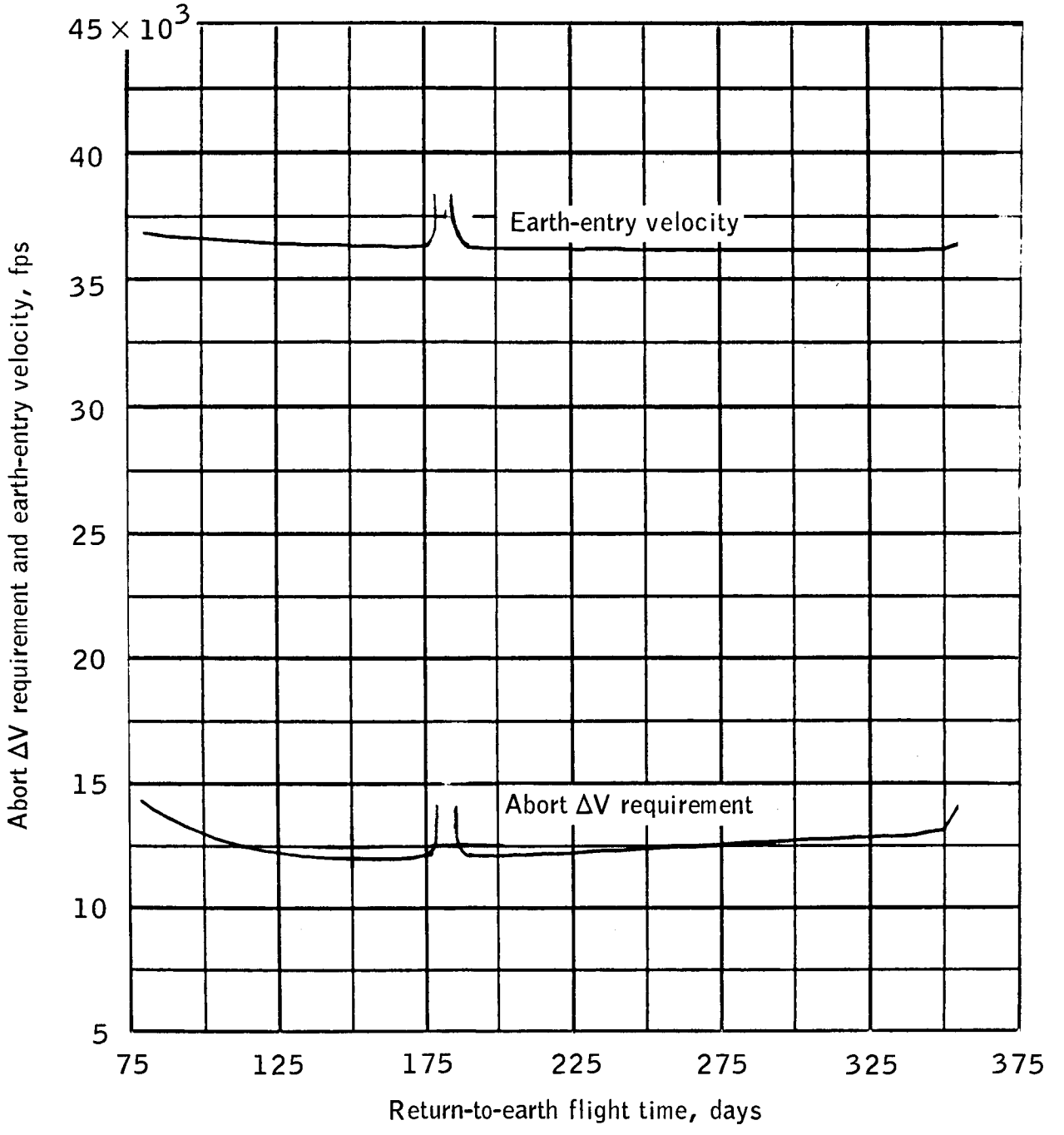

(f) Elapsed time to abort is 30 days after TMI.

Figure 5.- Continued.



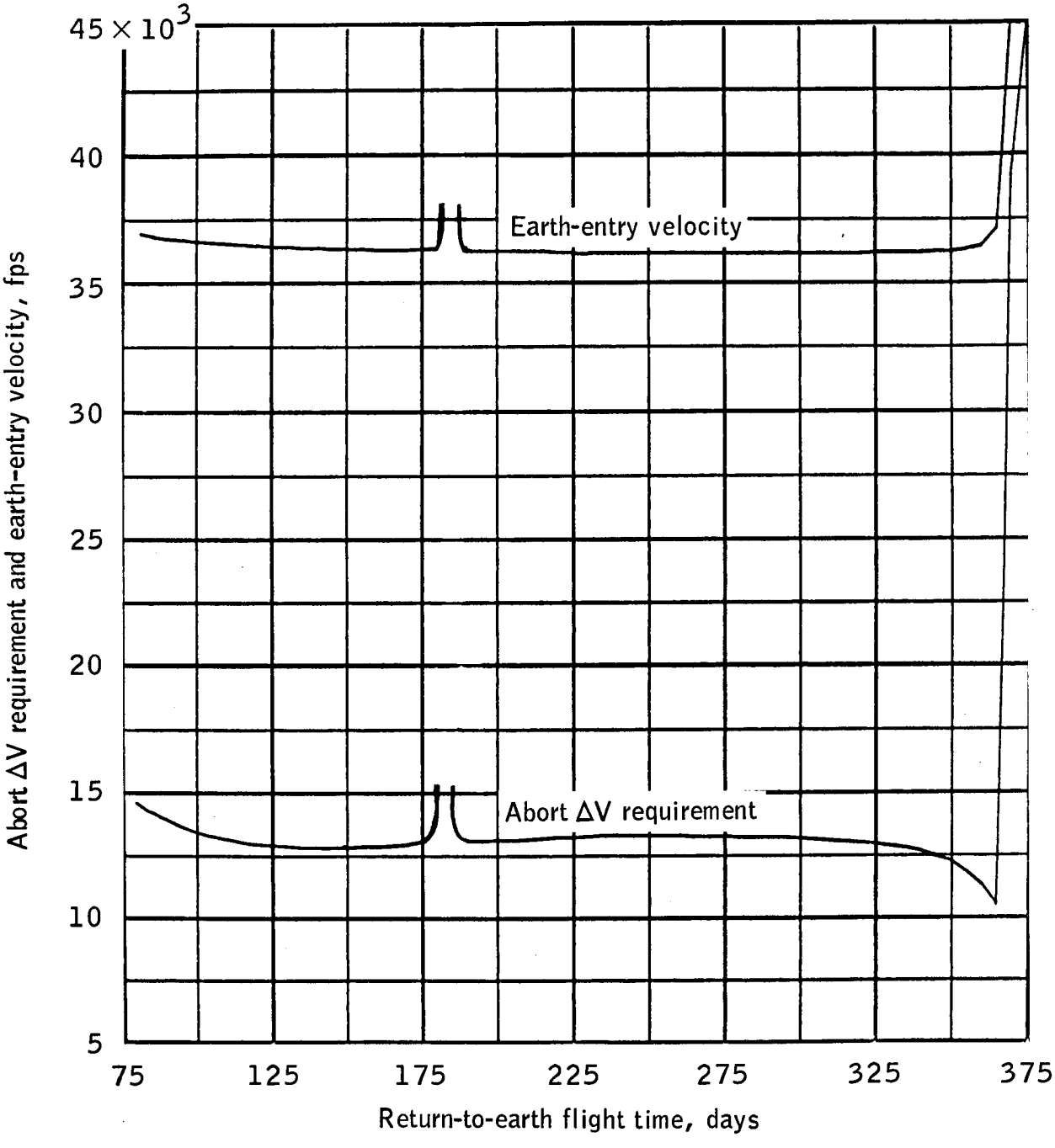

(g) Elapsed time to abort is 35 days after TMI.

Figure 5.- Continued.



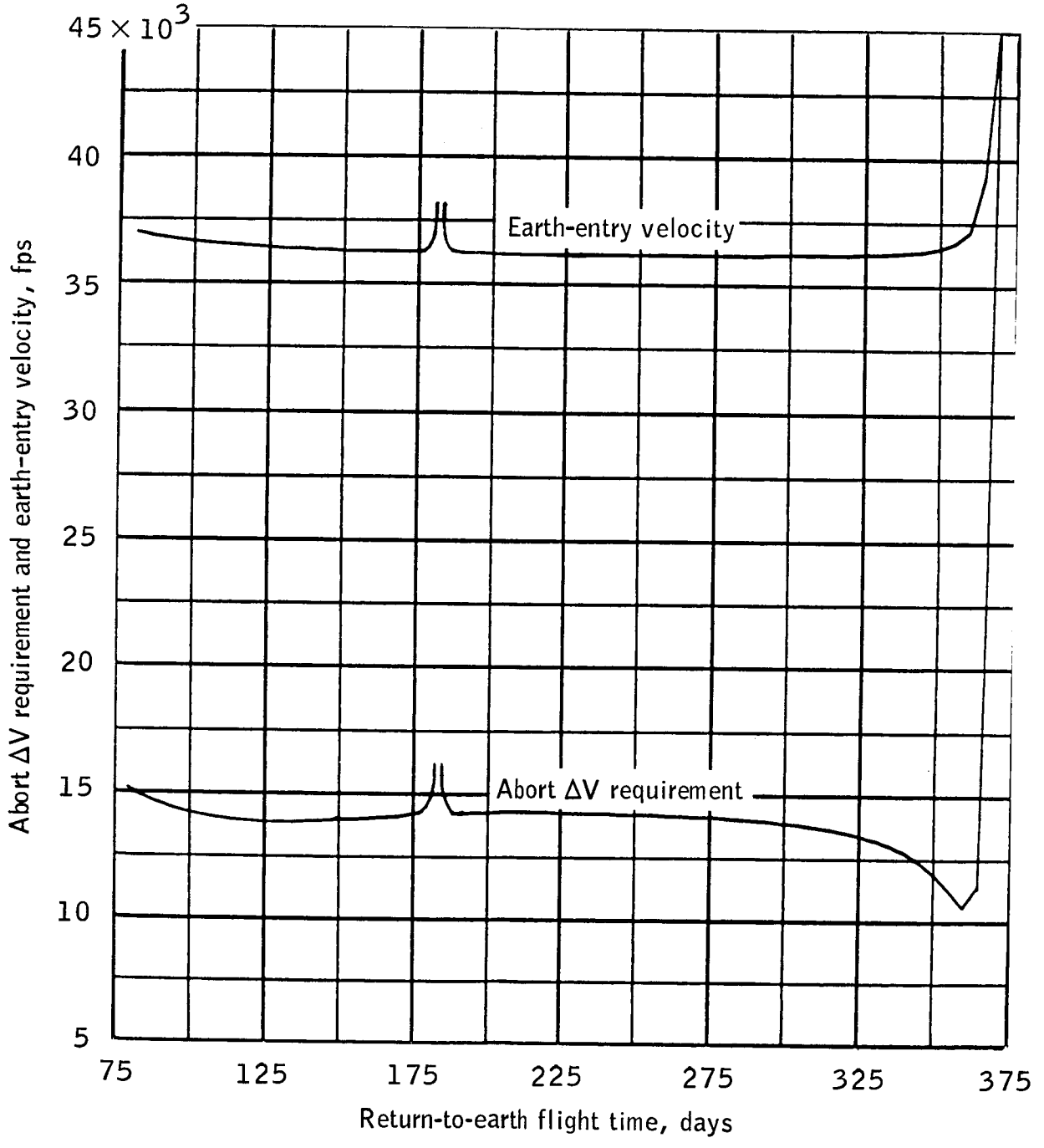

(h) Elapsed time to abort is 40 days after TMI.

Figure 5.- Continued.



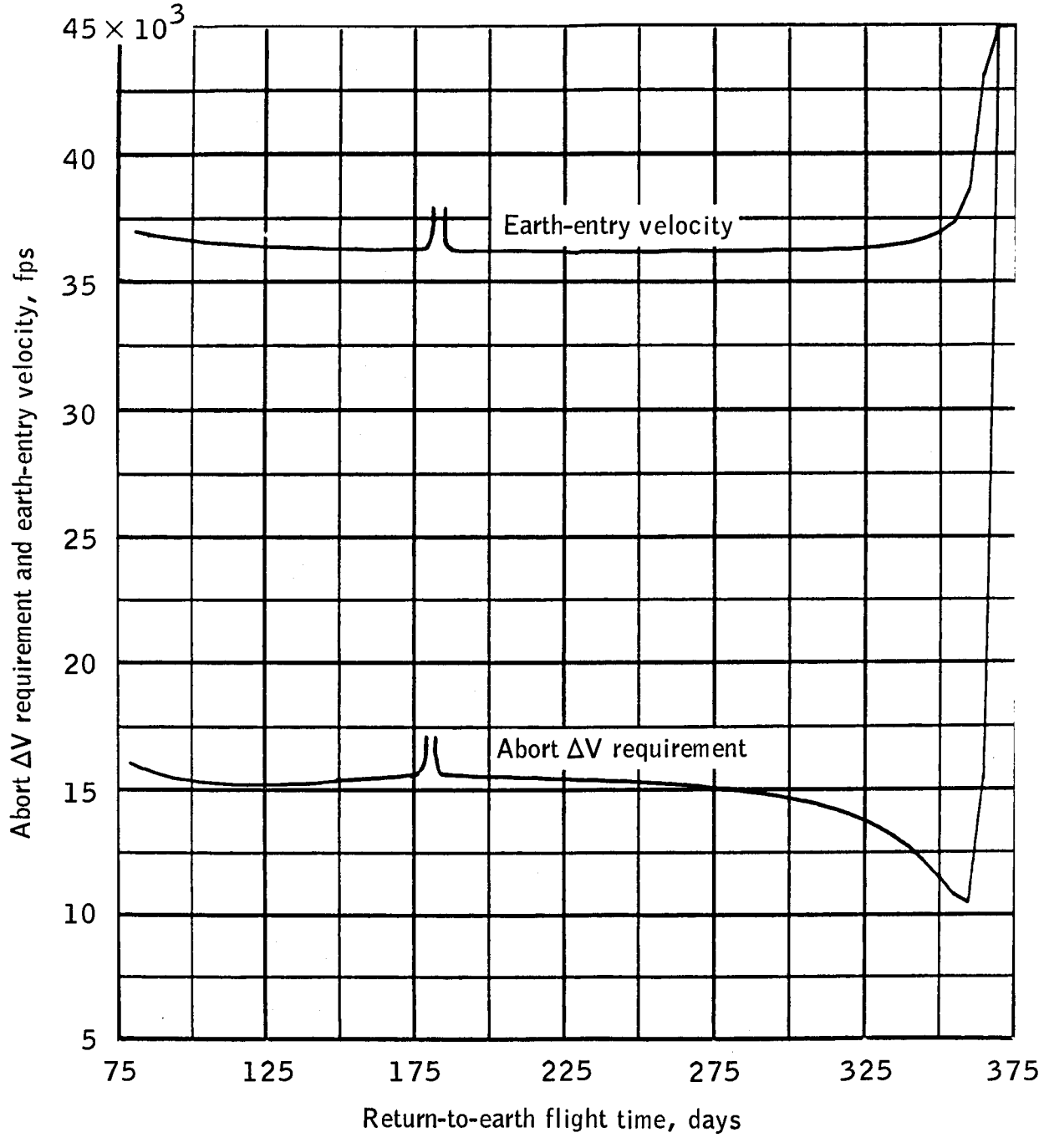

(i) Elapsed time to abort is 45 days after TMI.

Figure 5.- Continued.



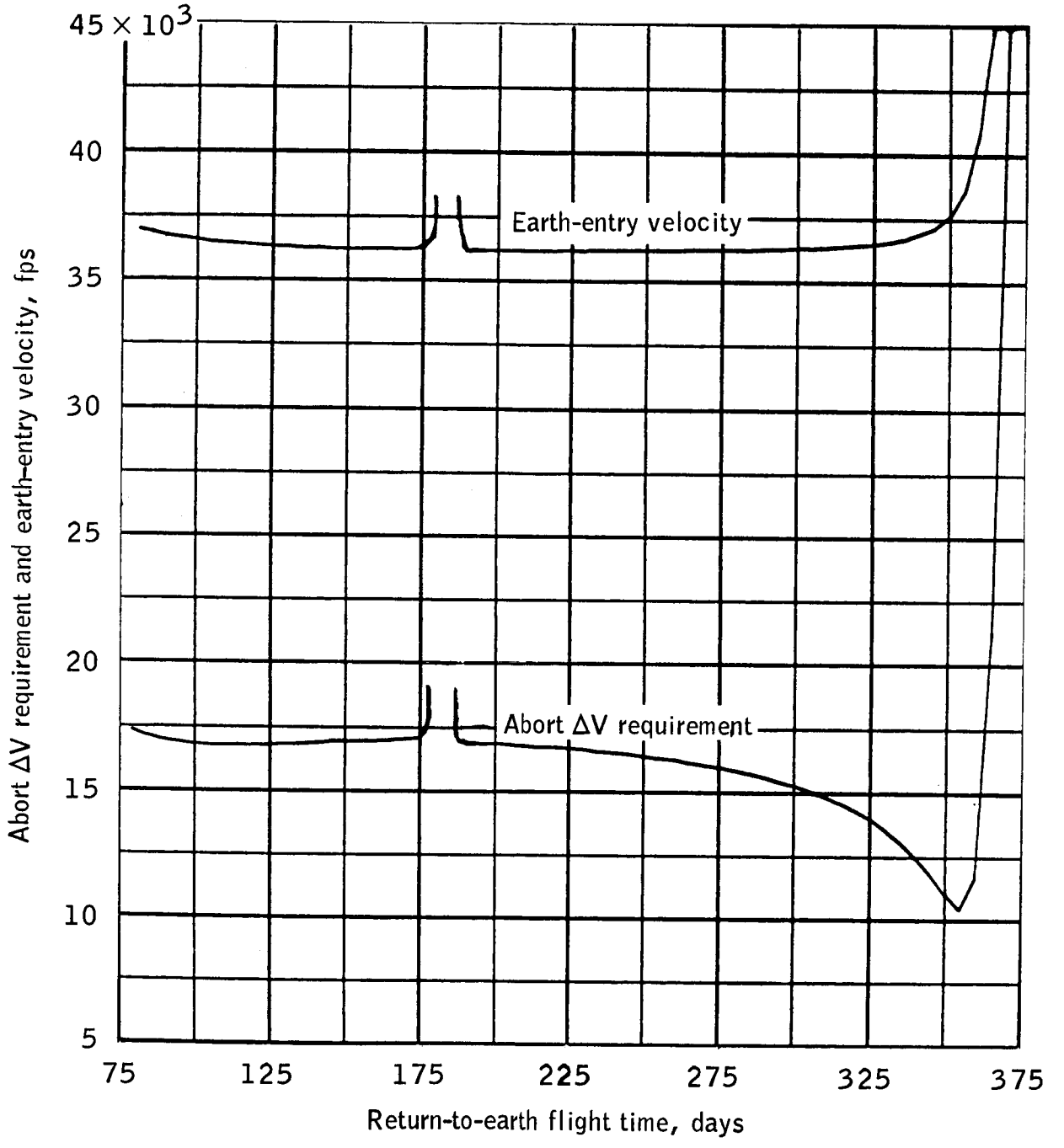

(j) Elapsed time to abort is 50 days after TMI.

Figure 5.- Continued.



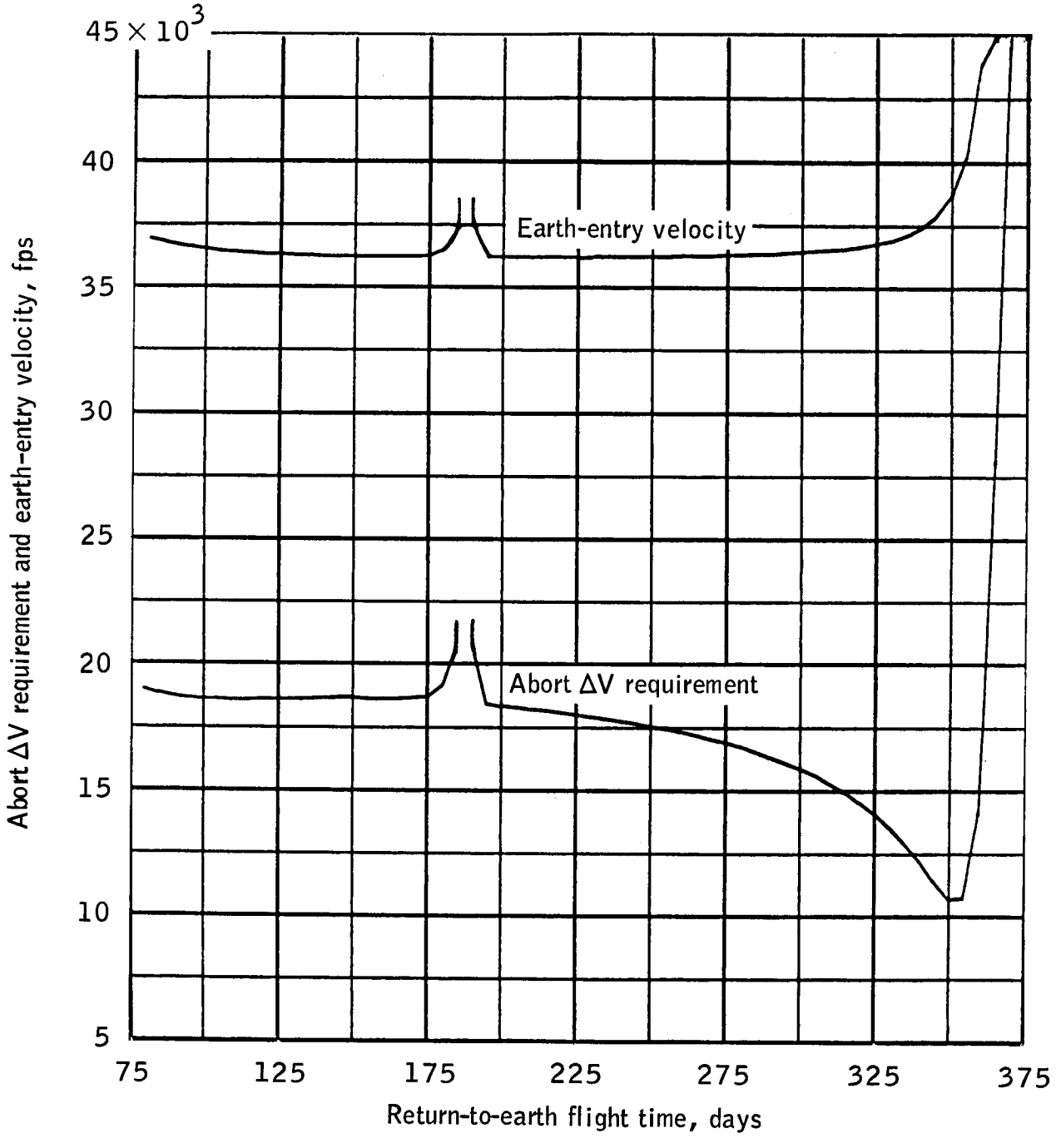

(k) Elapsed time to abort is 55 days after TMI.

Figure 5.- Continued.



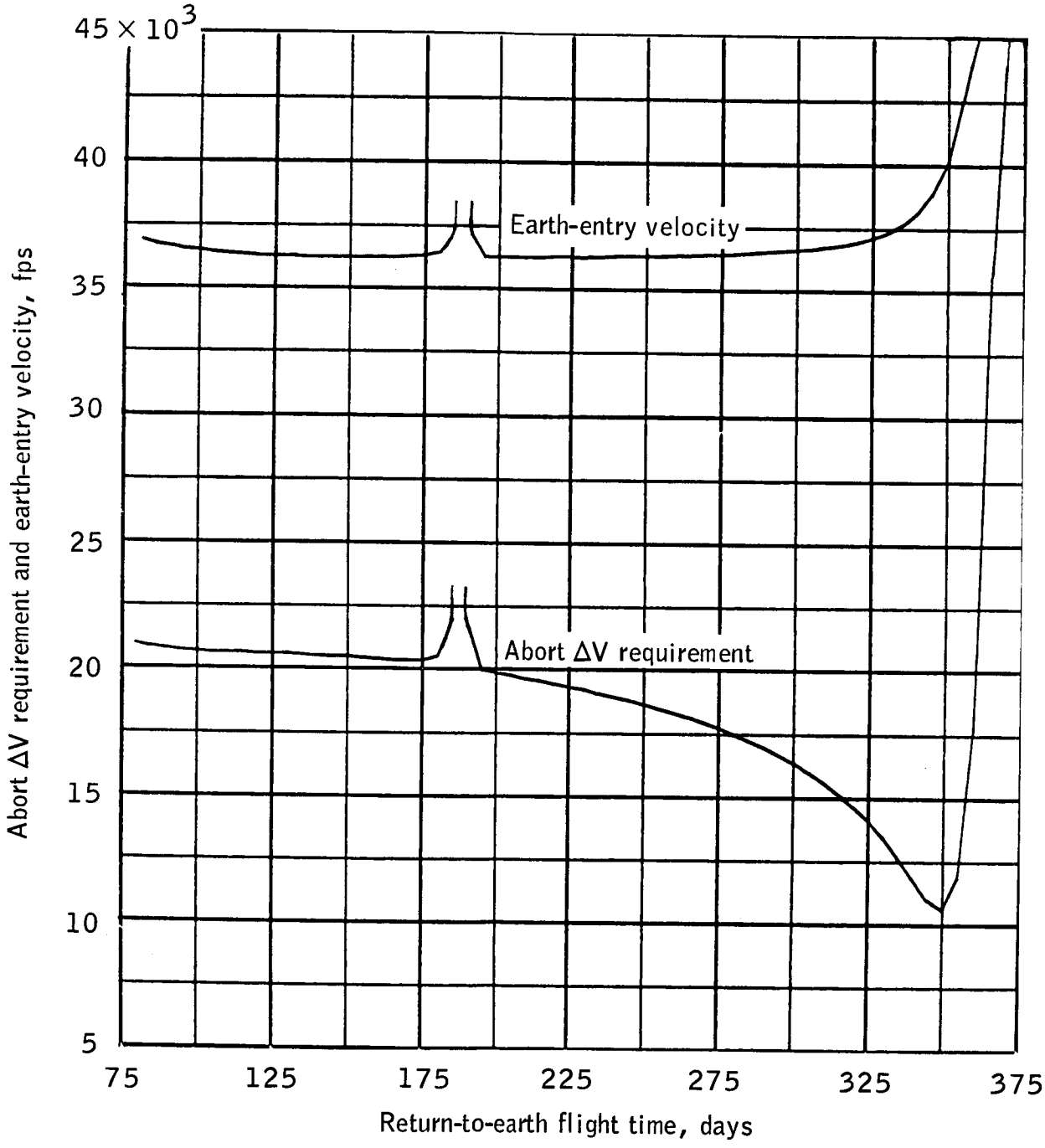

(l) Elapsed time to abort is 60 days after TMI.

Figure 5.- Continued.



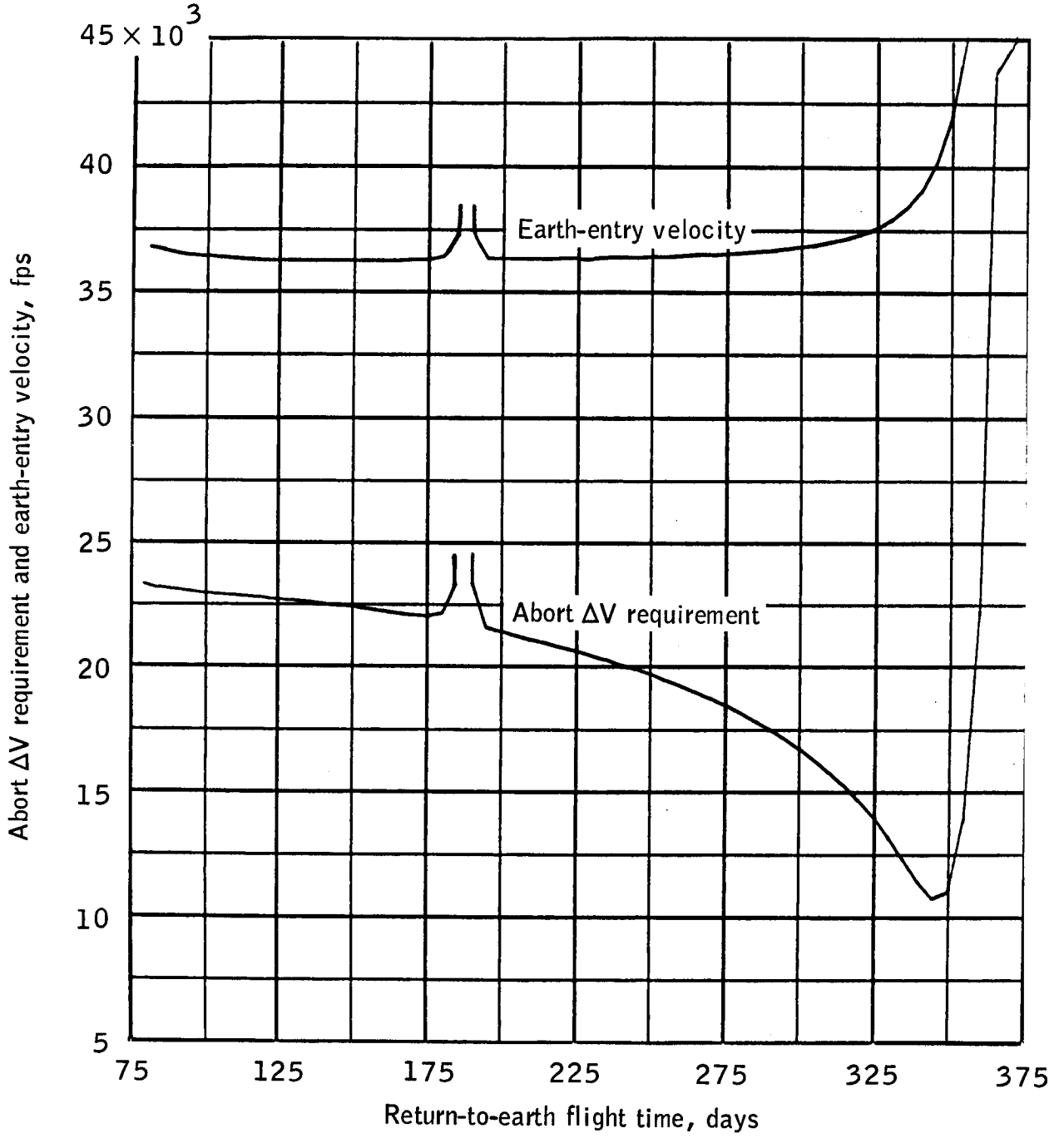

(m) Elapsed time to abort is 65 days after TMI.

Figure 5.- Continued.



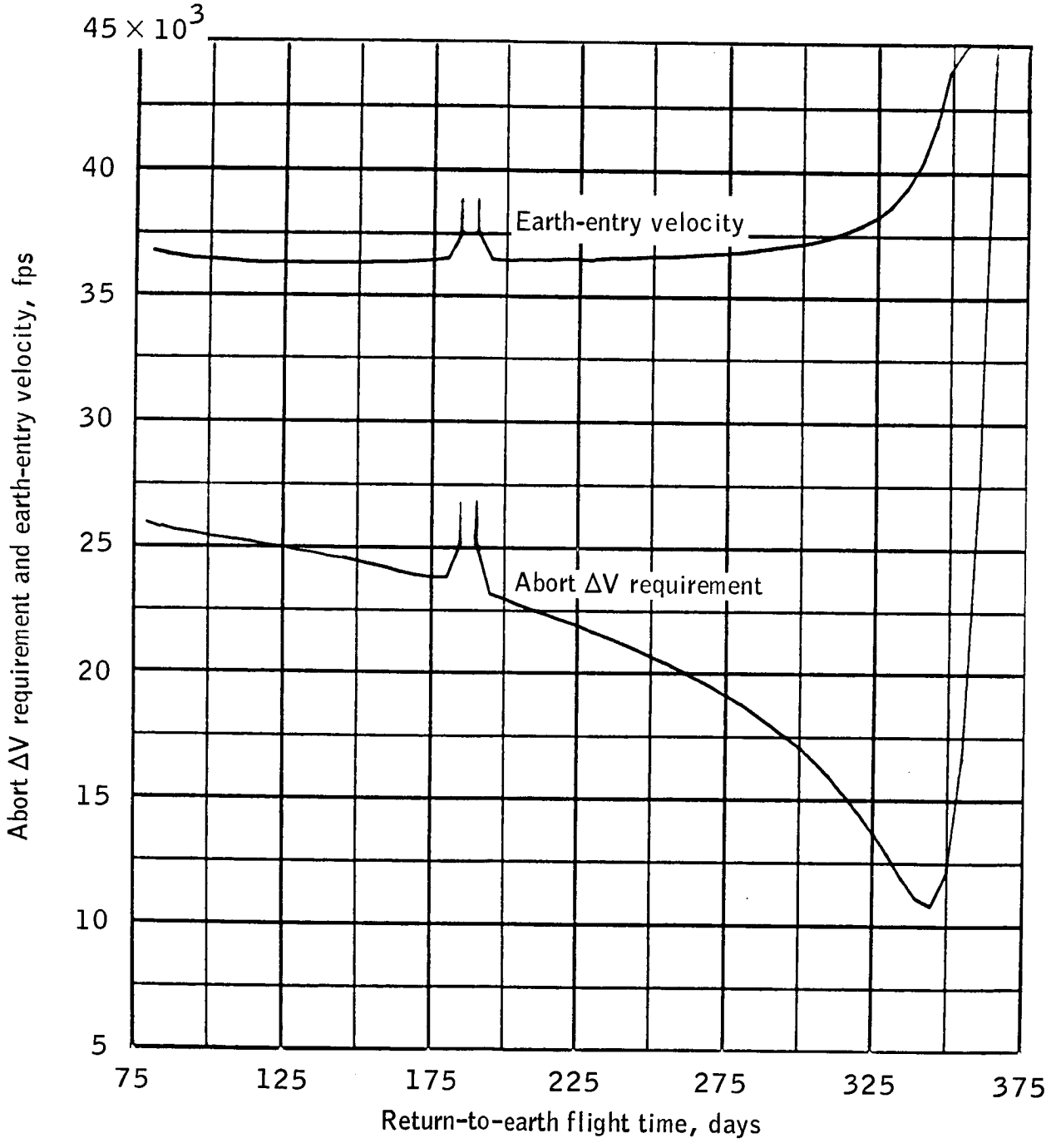

(n) Elapsed time to abort is 70 days after TMI.

Figure 5.- Continued.



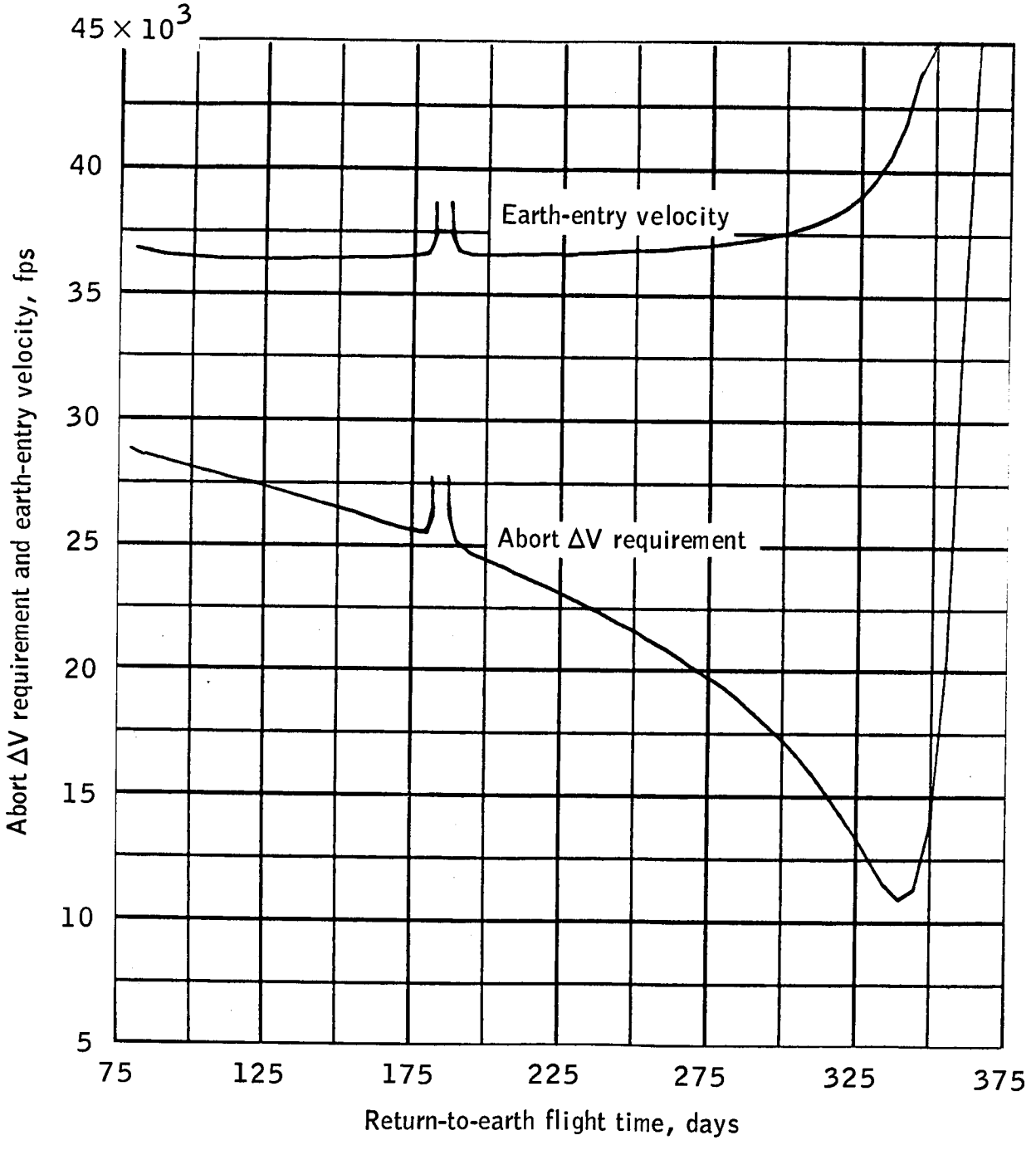

(o) Elapsed time to abort is 75 days after TMI.

Figure 5.- Continued.



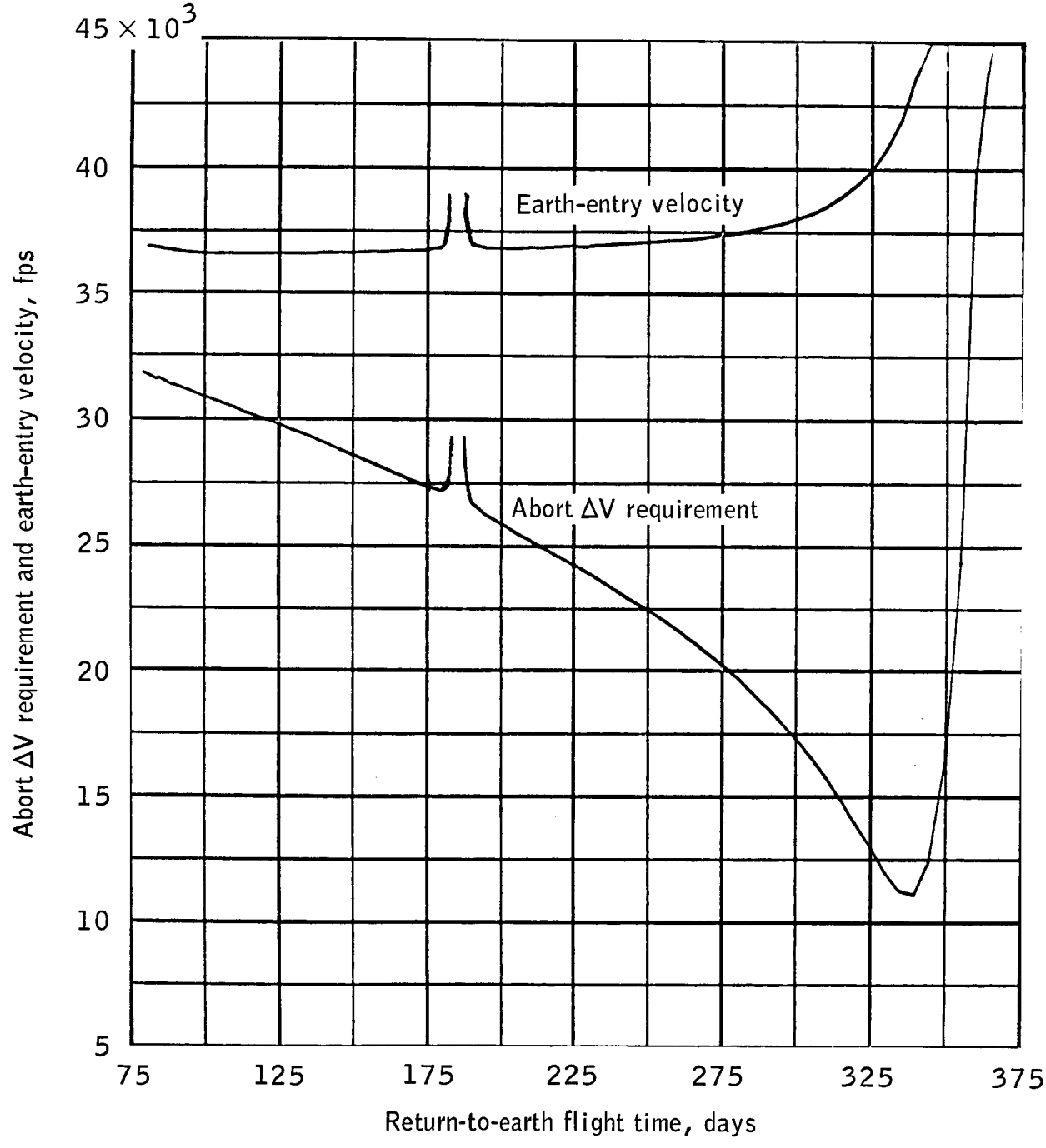

(p) Elapsed time to abort is 80 days after TMI.

Figure 5.- Continued.



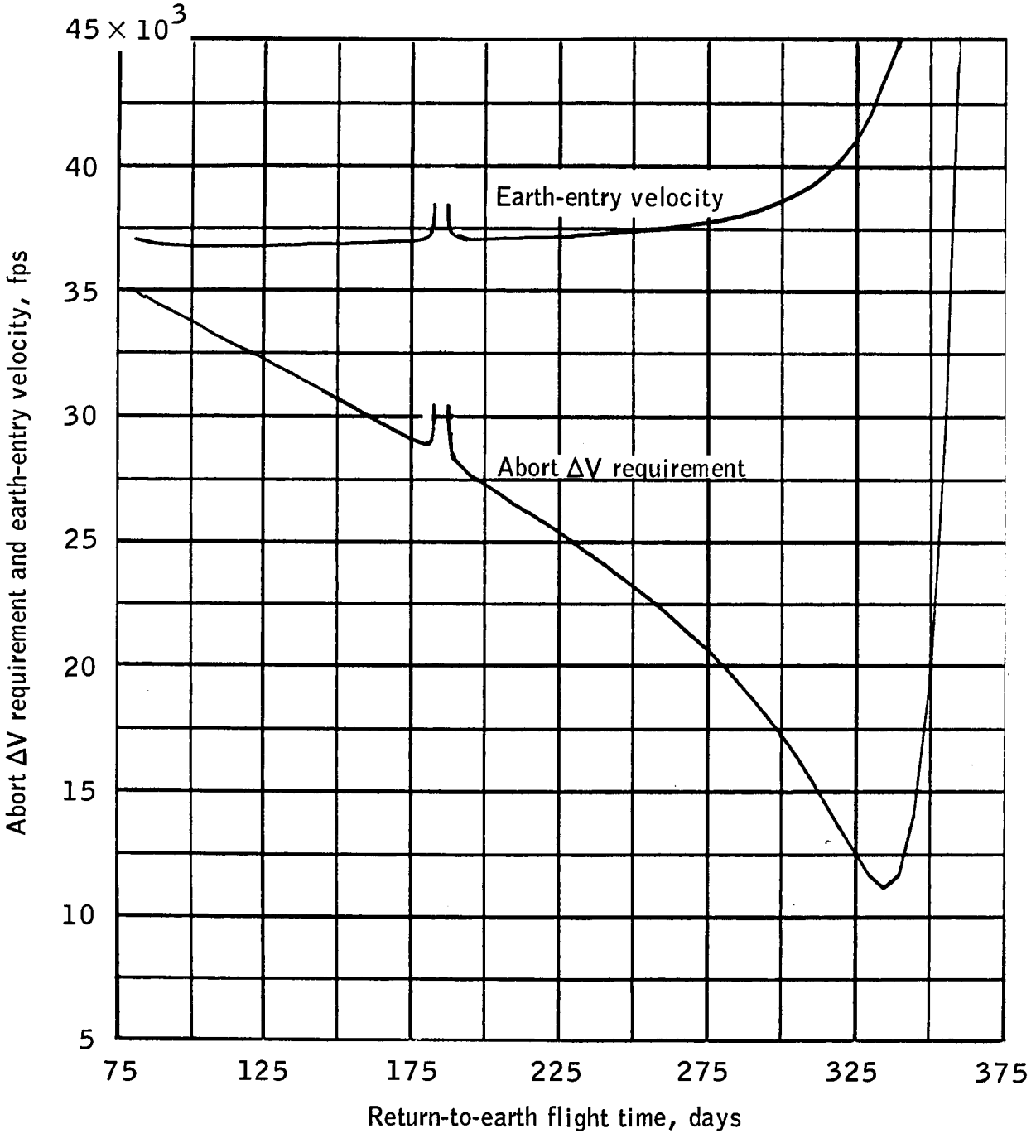

(q) Elapsed time to abort is 85 days after TMI.

Figure 5.- Continued.



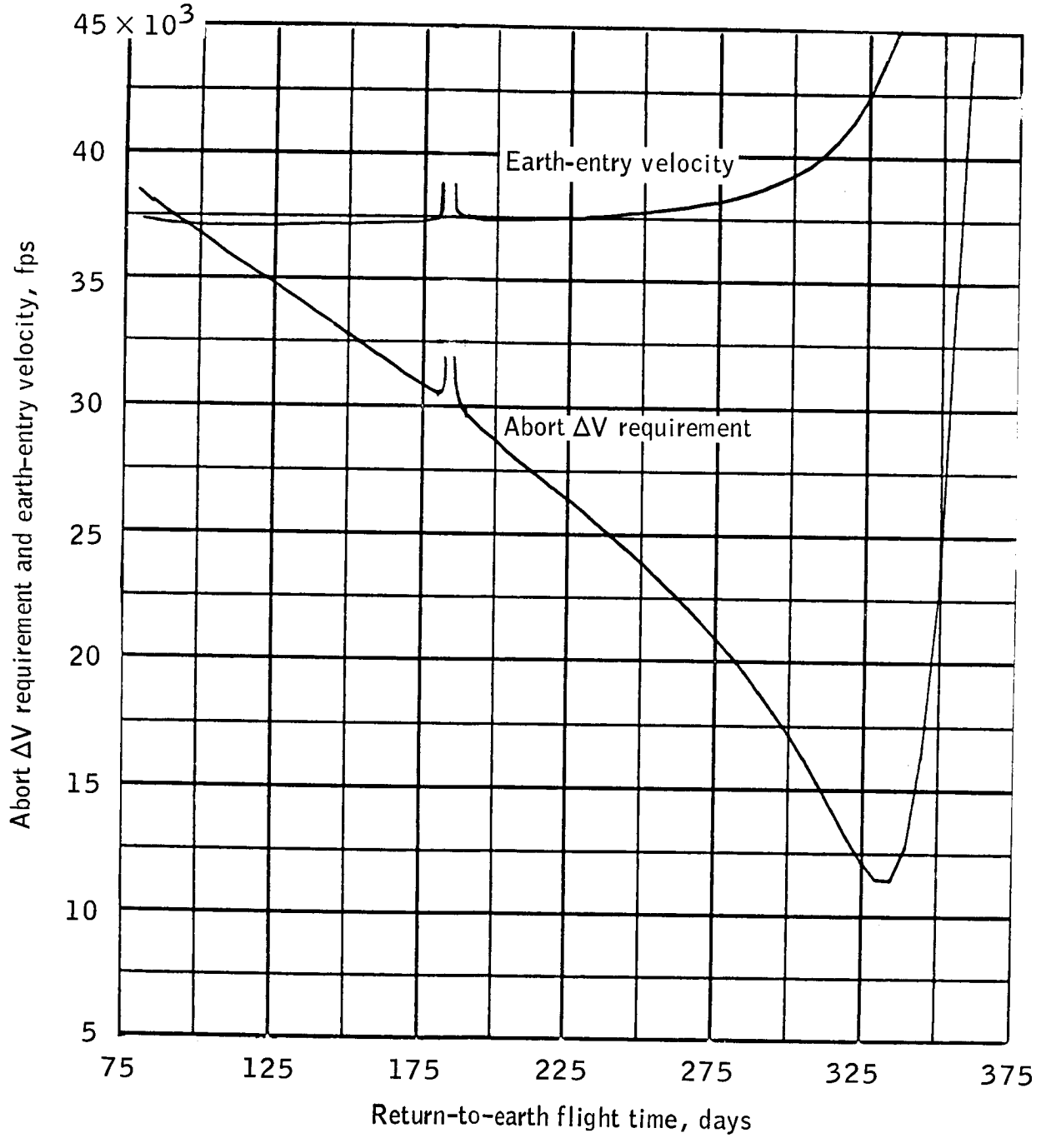

(r) Elapsed time to abort is 90 days after TMI.

Figure 5.- Continued.



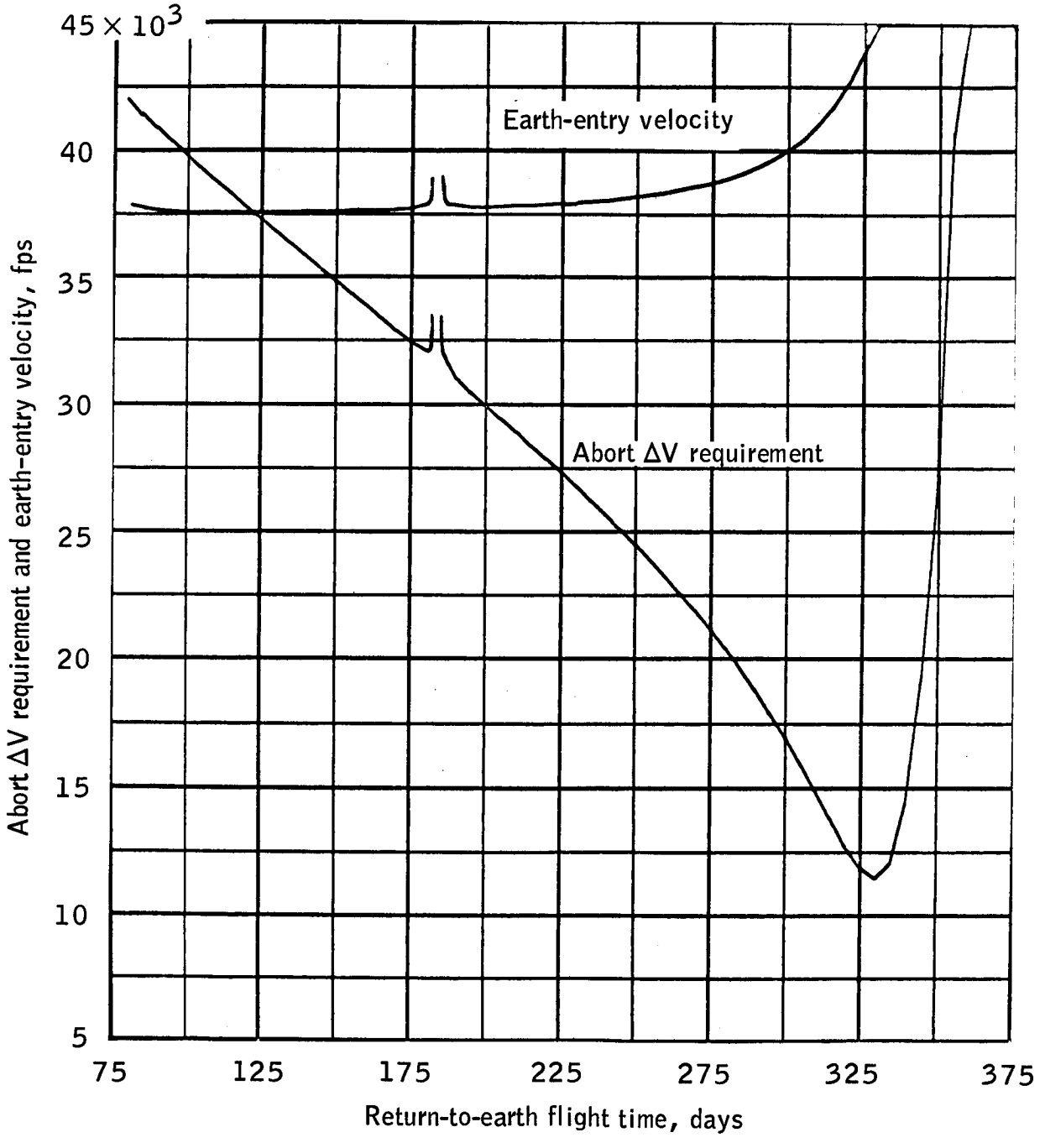

(s) Elapsed time to abort is 95 days after TMI.

Figure 5.- Continued.



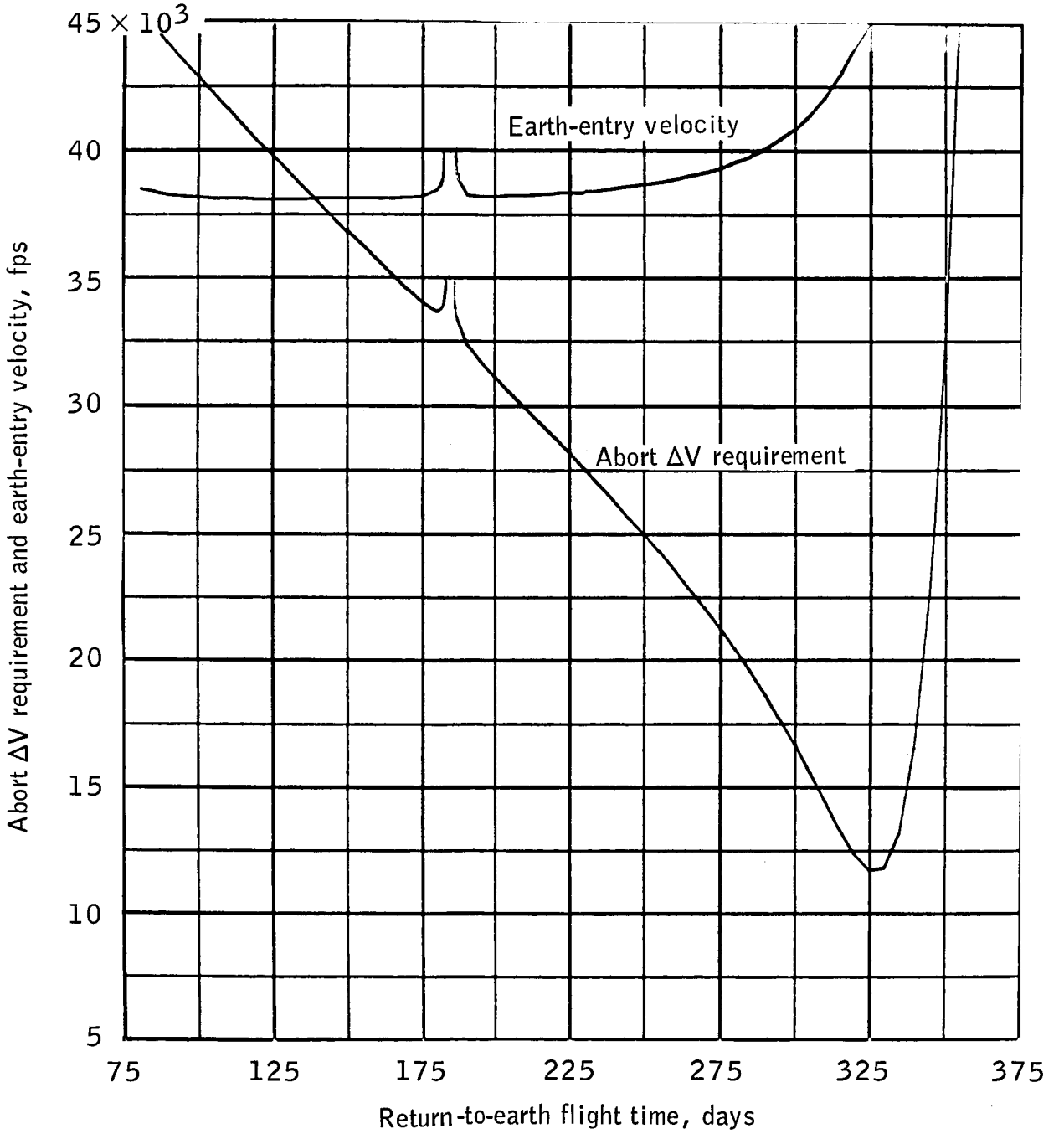

(t) Elapsed time to abort is 100 days after TMI.

Figure 5.- Continued.



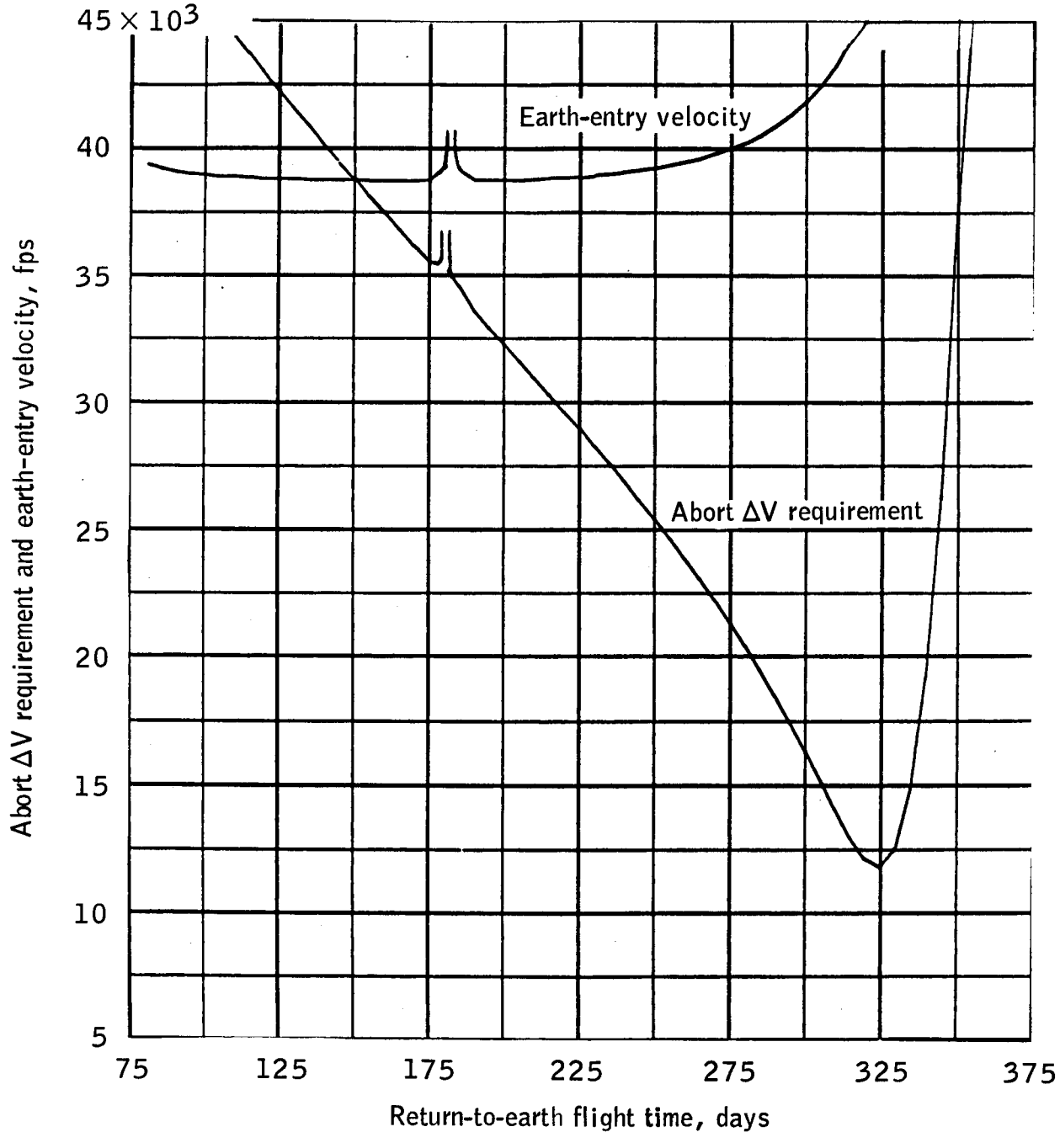

(u) Elapsed time to abort is 105 days after TMI.

Figure 5.- Continued.



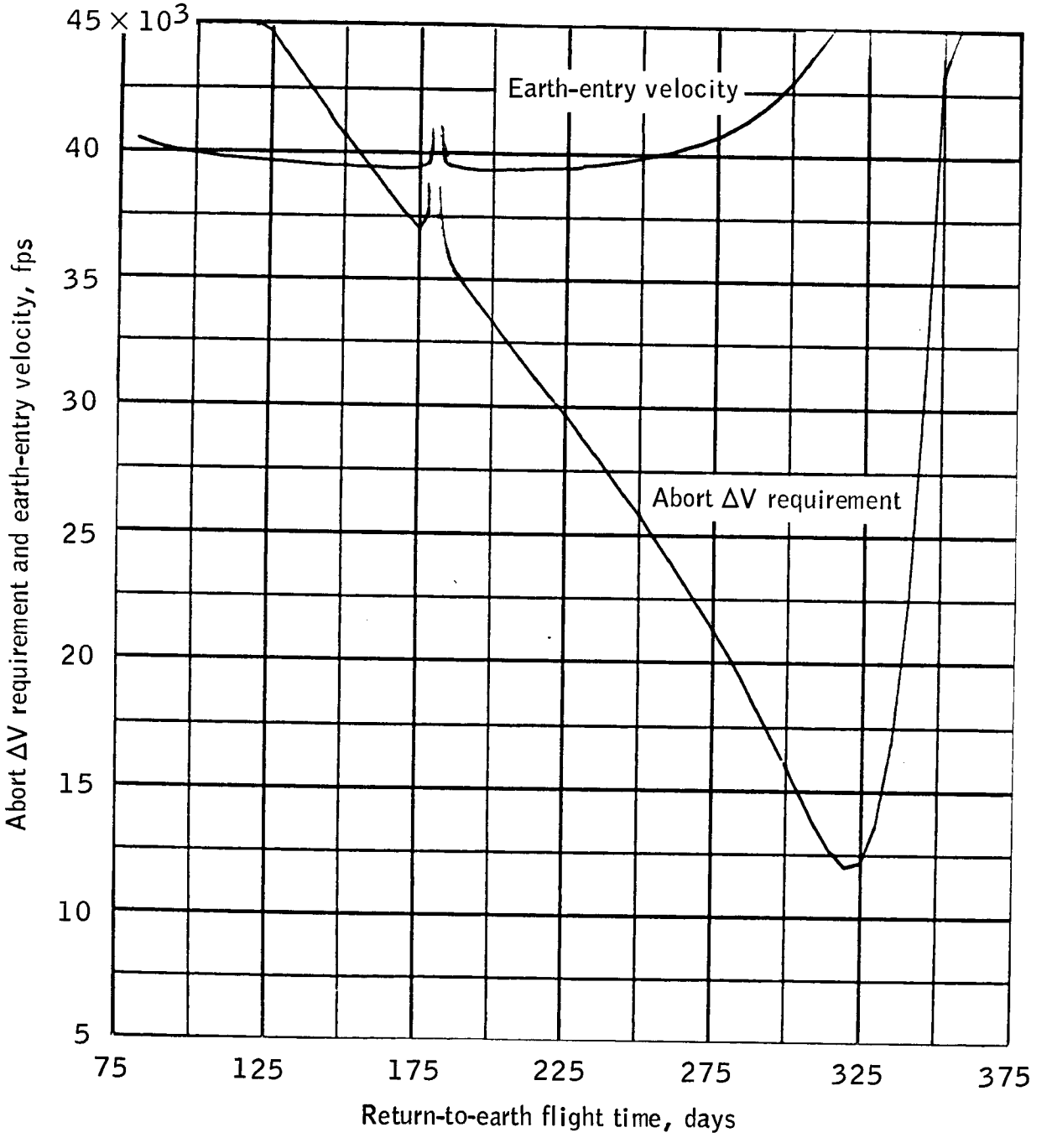

(v) Elapsed time to abort is 110 days after TMI.

Figure 5.- Continued.



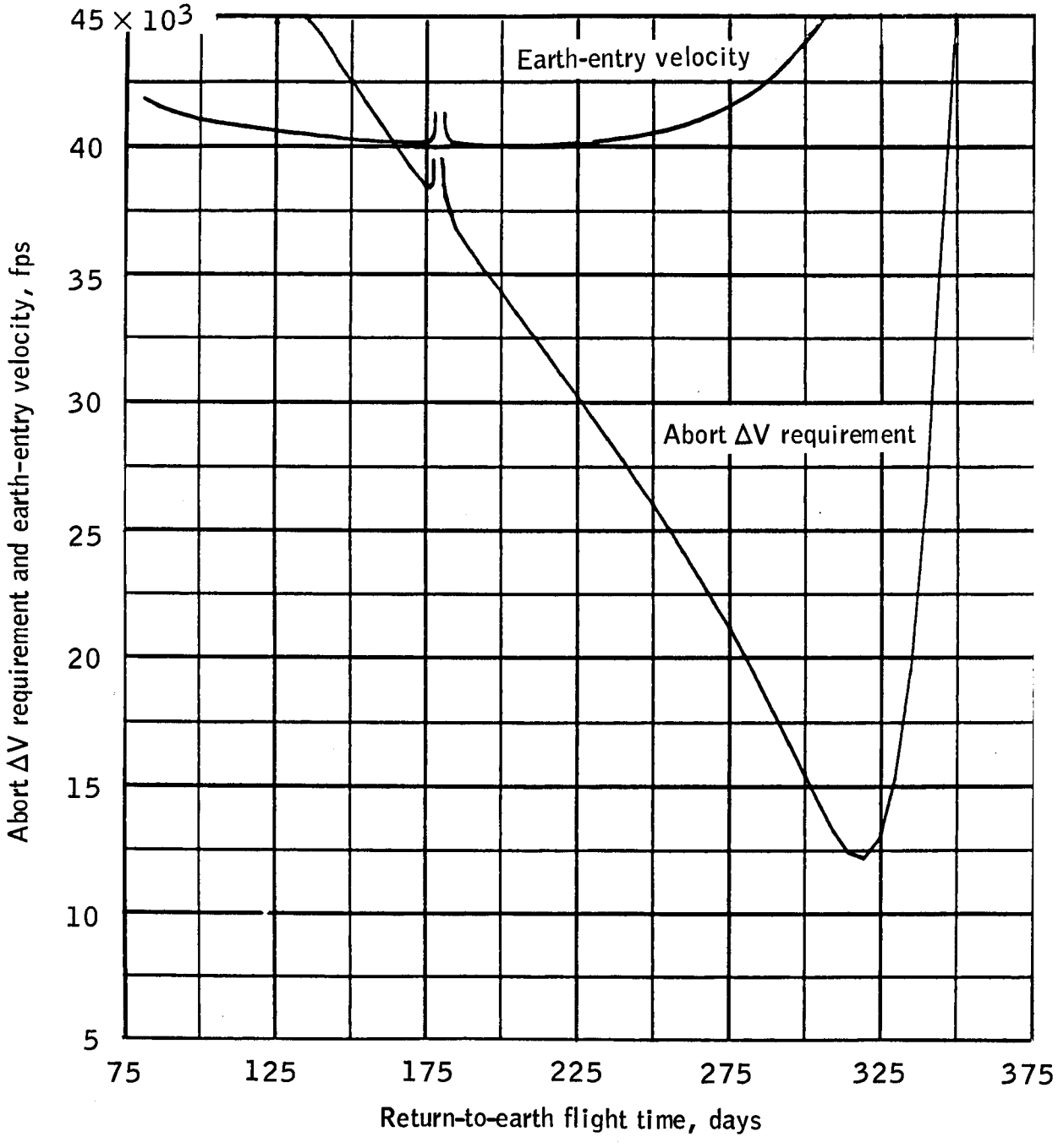

(w) Elapsed time to abort is 115 days after TMI.

Figure 5.- Continued.



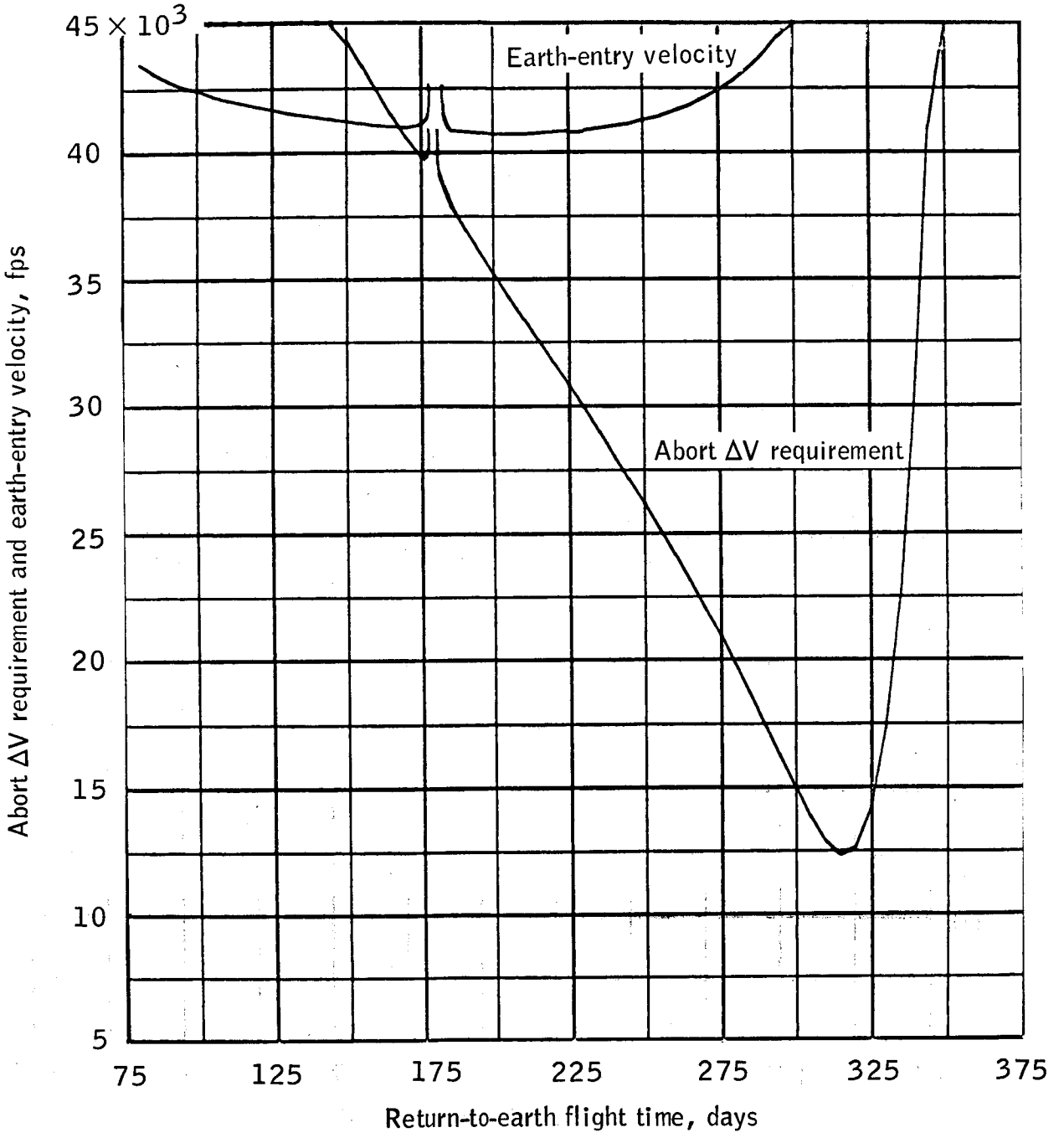

(x) Elapsed time to abort is 120 days after TMI.

Figure 5.- Continued.



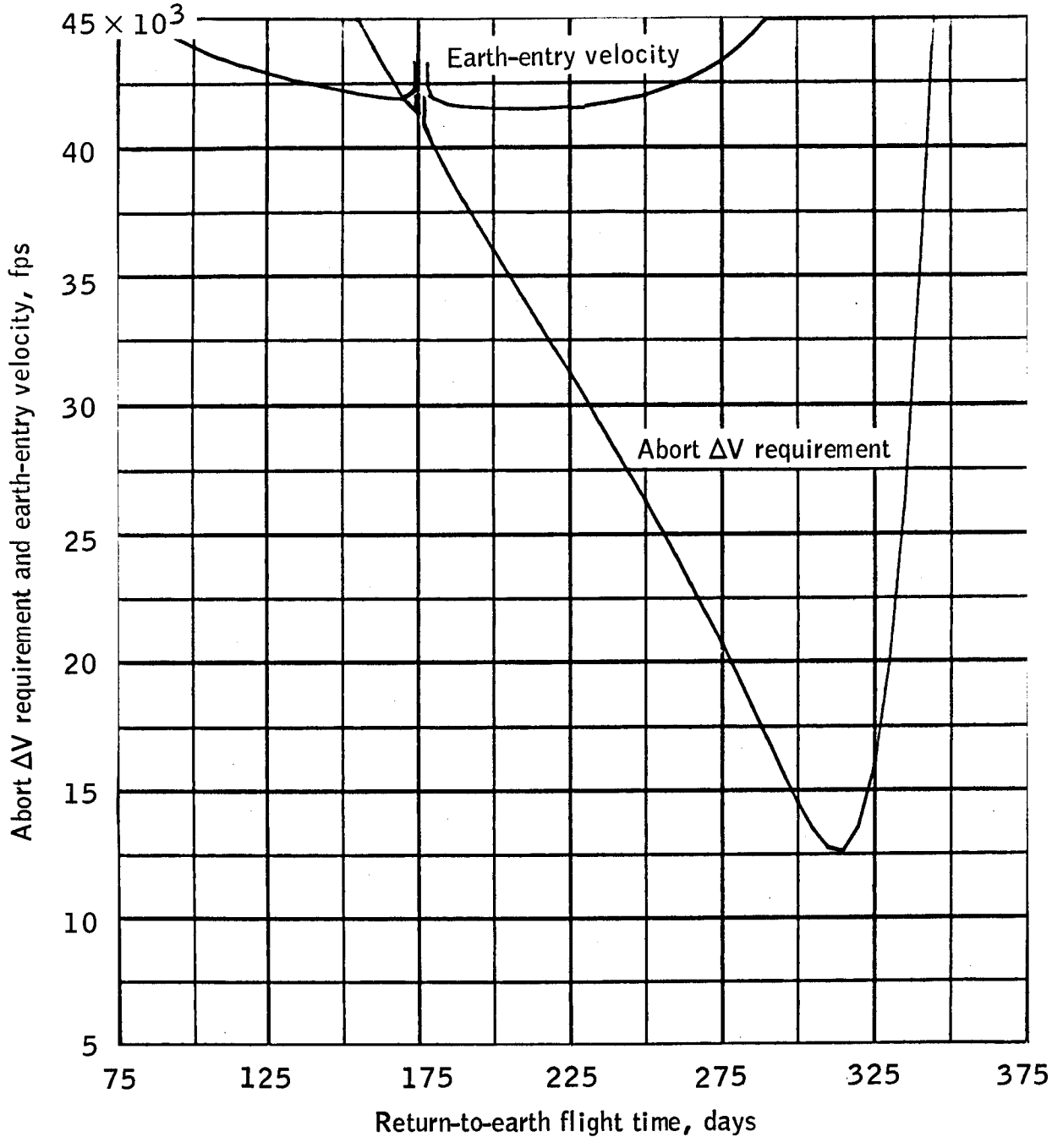

(y) Elapsed time to abort is 125 days after TMI.

Figure 5.- Continued.



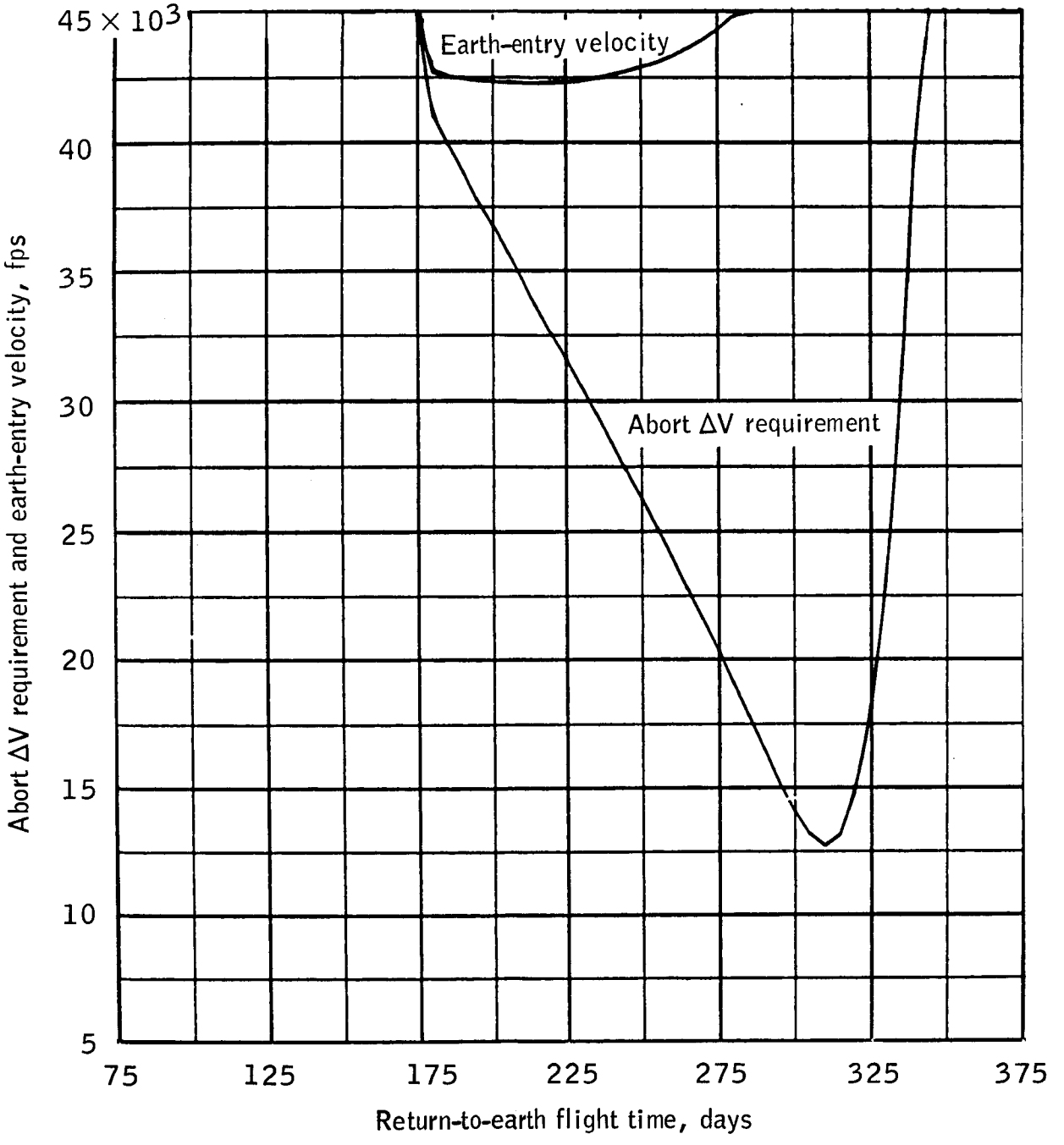

(z) Elapsed time to abort is 130 days after TMI.

Figure 5.- Continued.



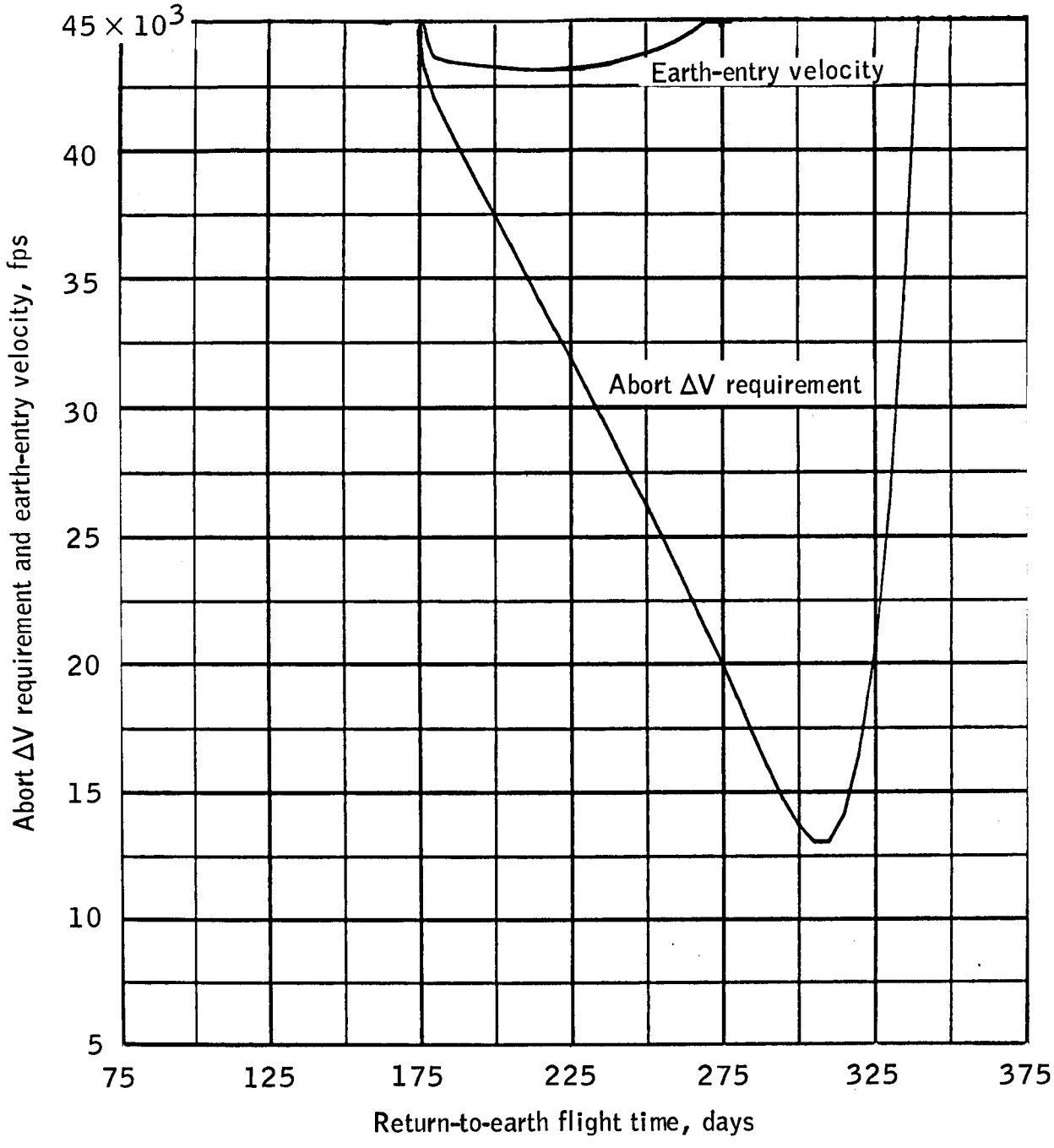

(aa) Elapsed time to abort is 135 days after TMI.

Figure 5.- Continued.



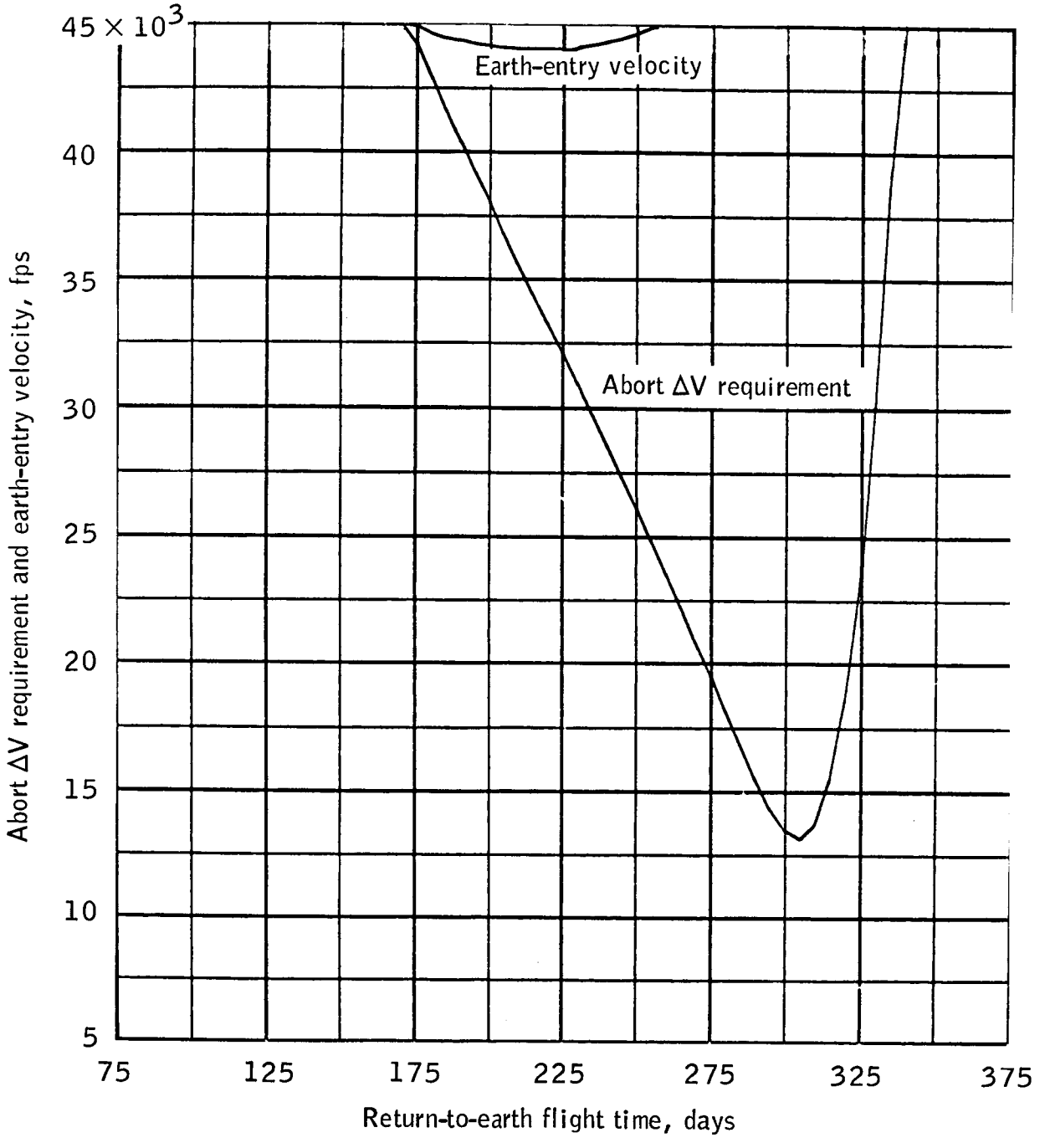

(bb) Elapsed time to abort is 140 days after TMI.

Figure 5.- Continued.



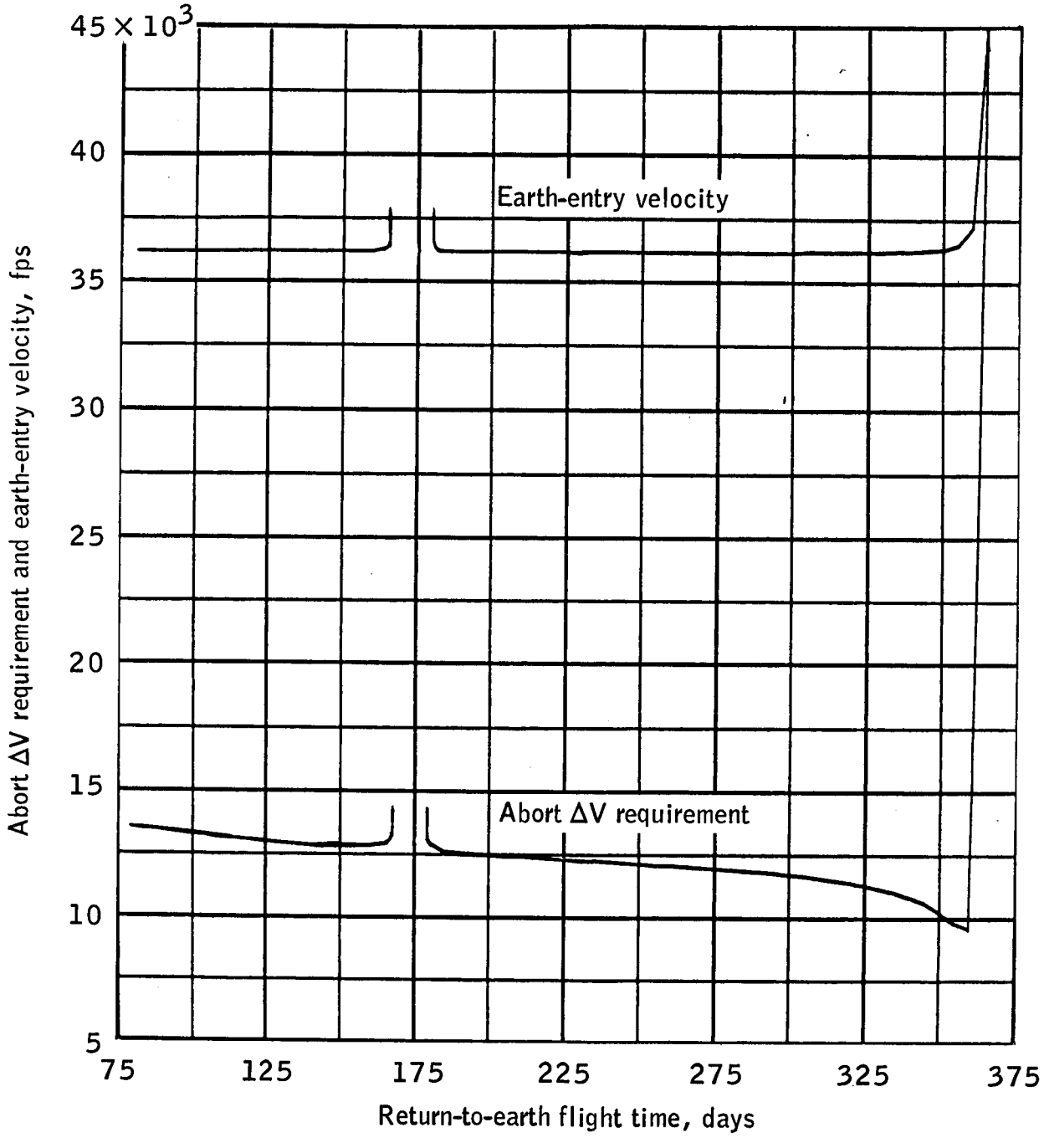

(cc) Elapsed time to abort is 145 days after TMI.

Figure 5.- Continued.



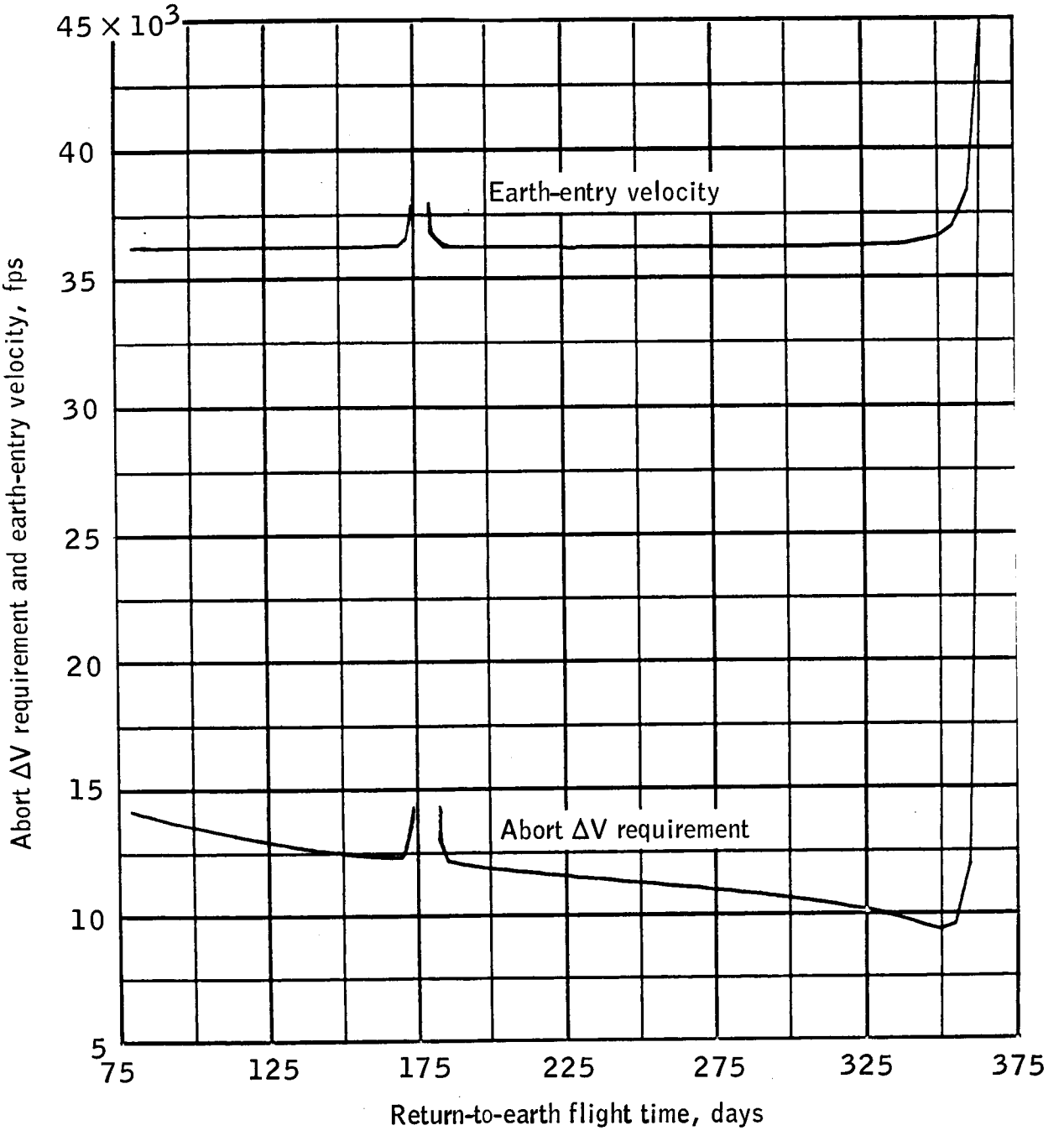

(dd) Elapsed time to abort is 150 days after TMI.

Figure 5.- Concluded.



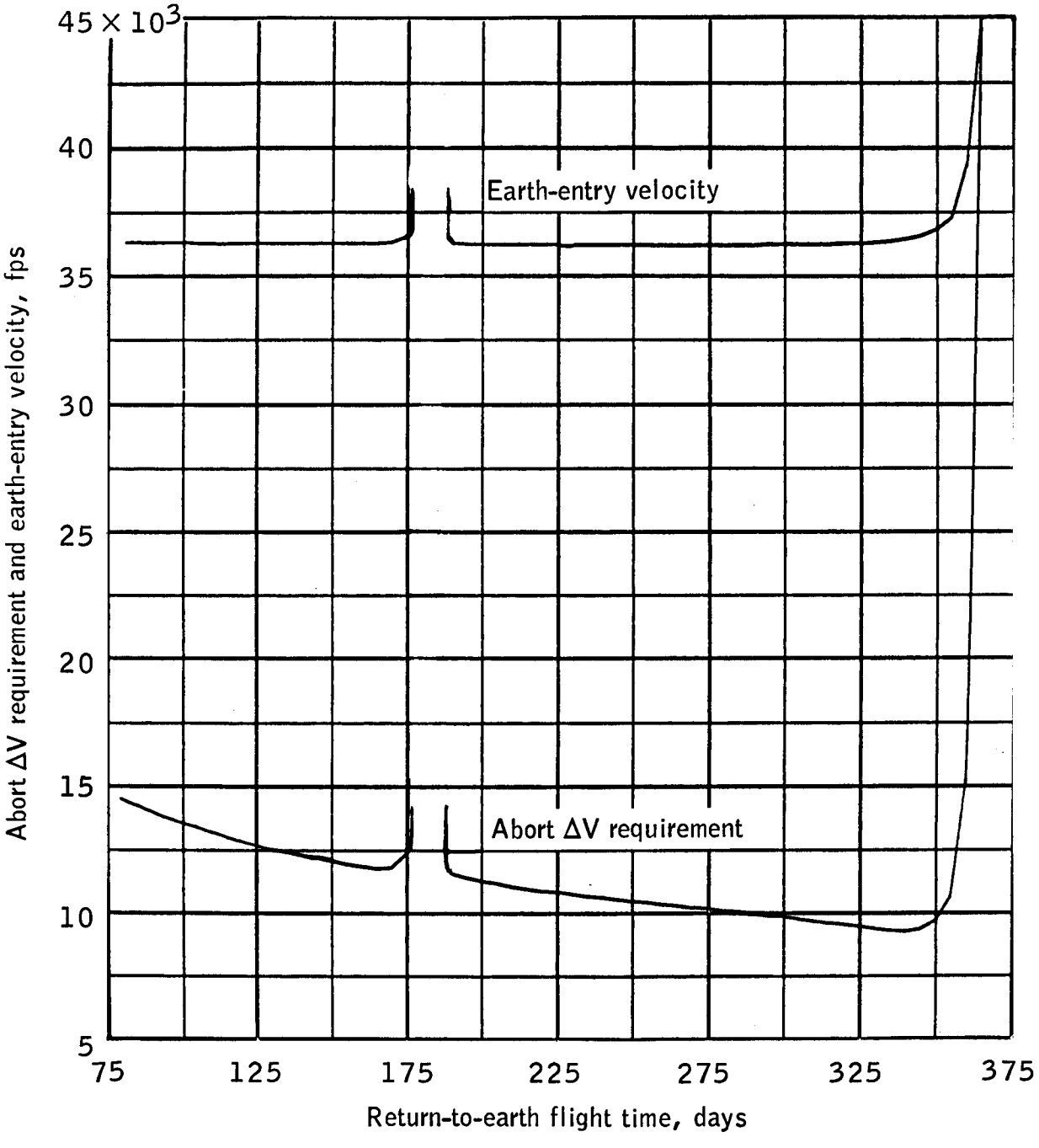

(a) Elapsed time to abort is 5 days after TMI.

Figure 6.- Velocity characteristics of heliocentric abort trajectories, 1979 Mars conjunction class mission.



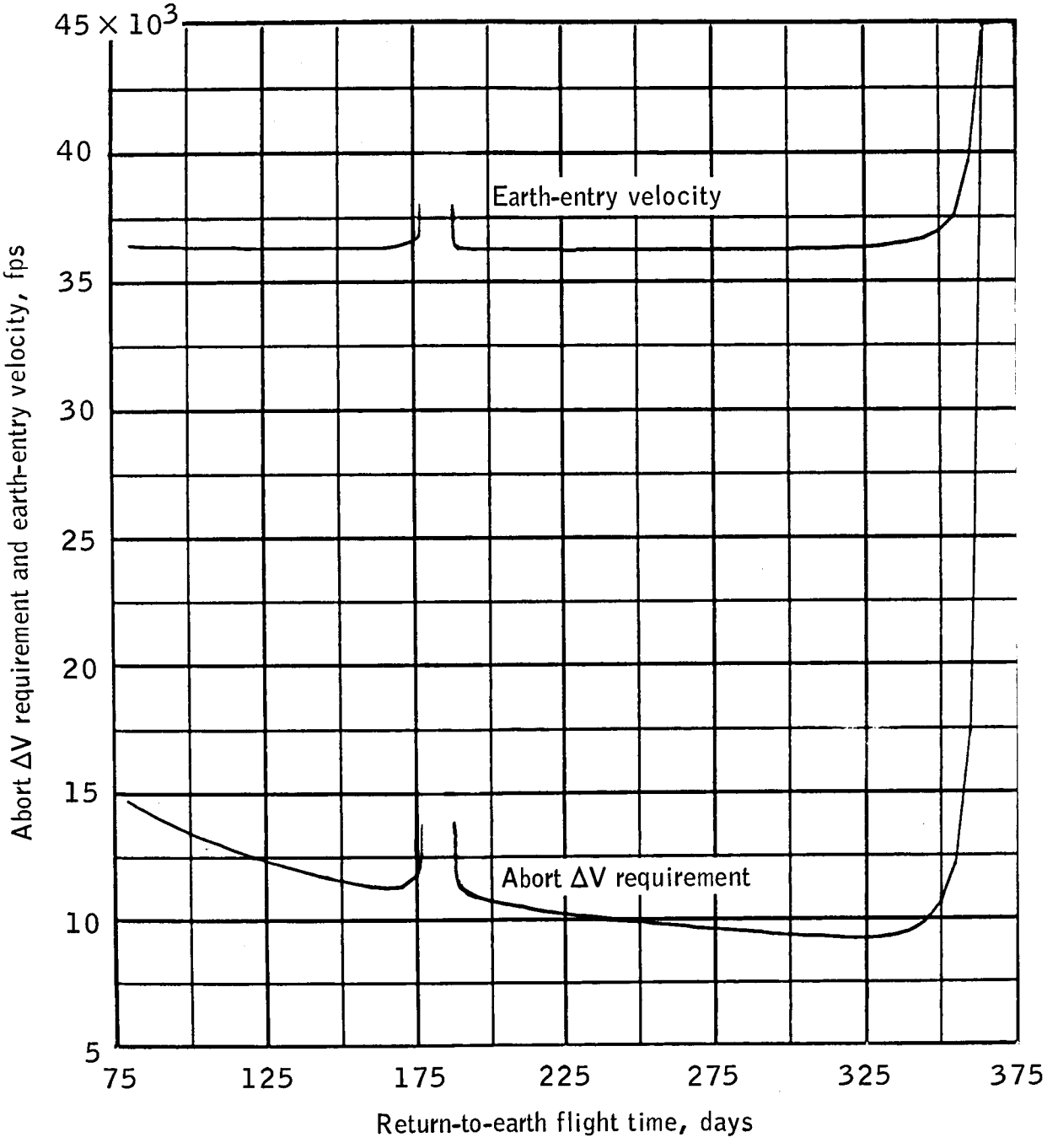

(b) Elapsed time to abort is 10 days after TMI.

Figure 6.- Continued.



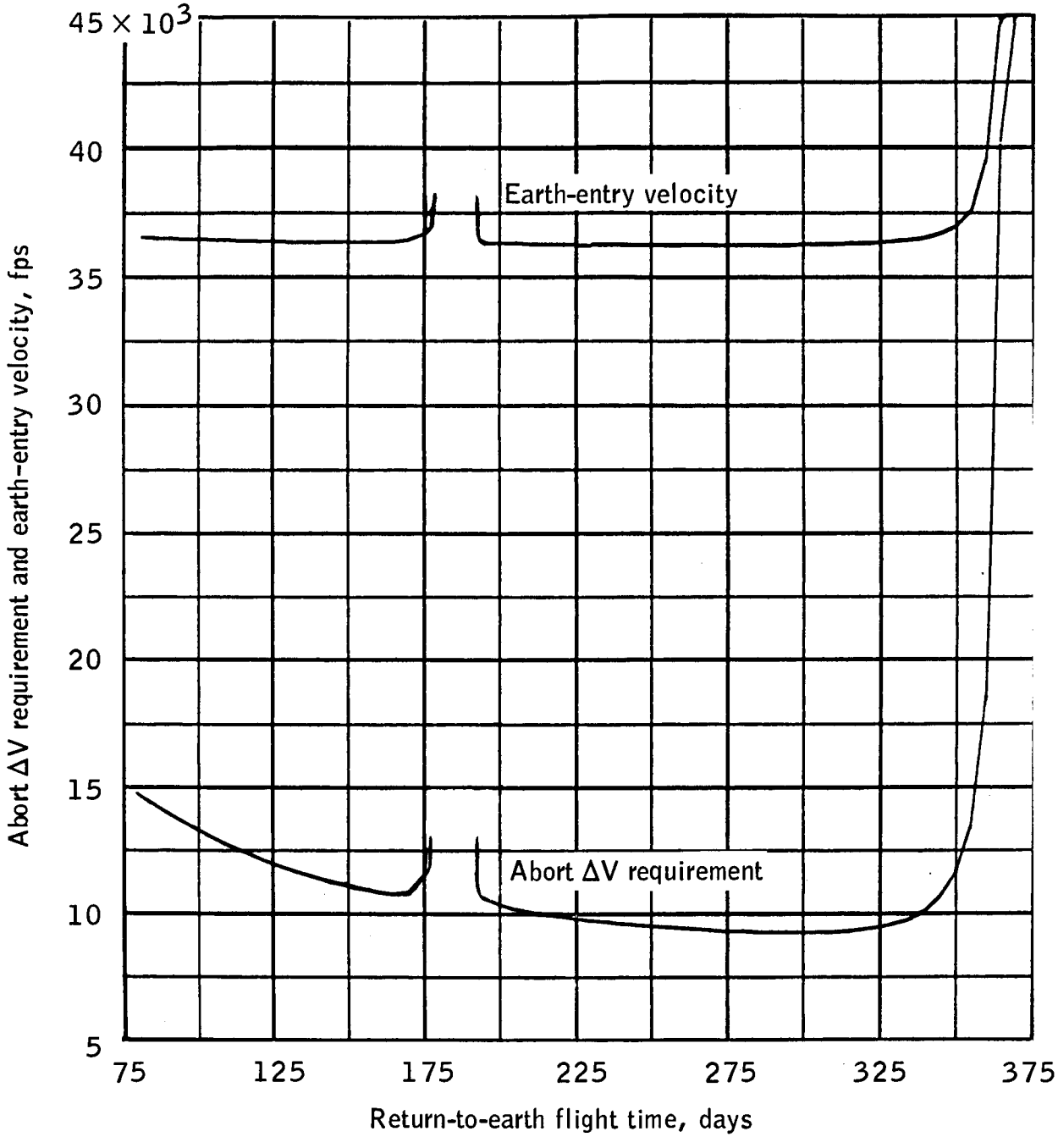

(c) Elapsed time to abort is 15 days after TMI.

Figure 6.- Continued.



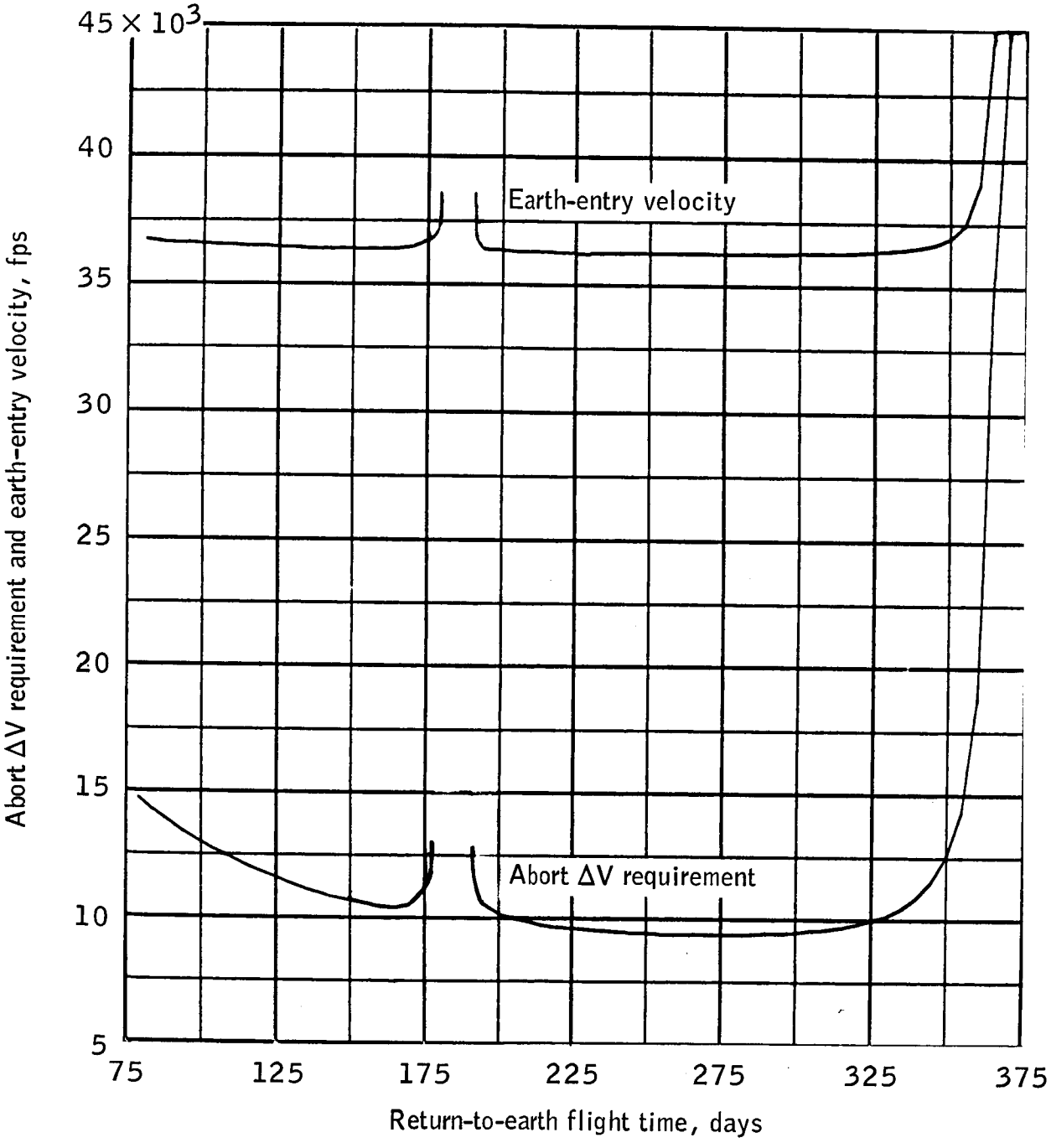

(d) Elapsed time to abort is 20 days after TMI.

Figure 6.- Continued.



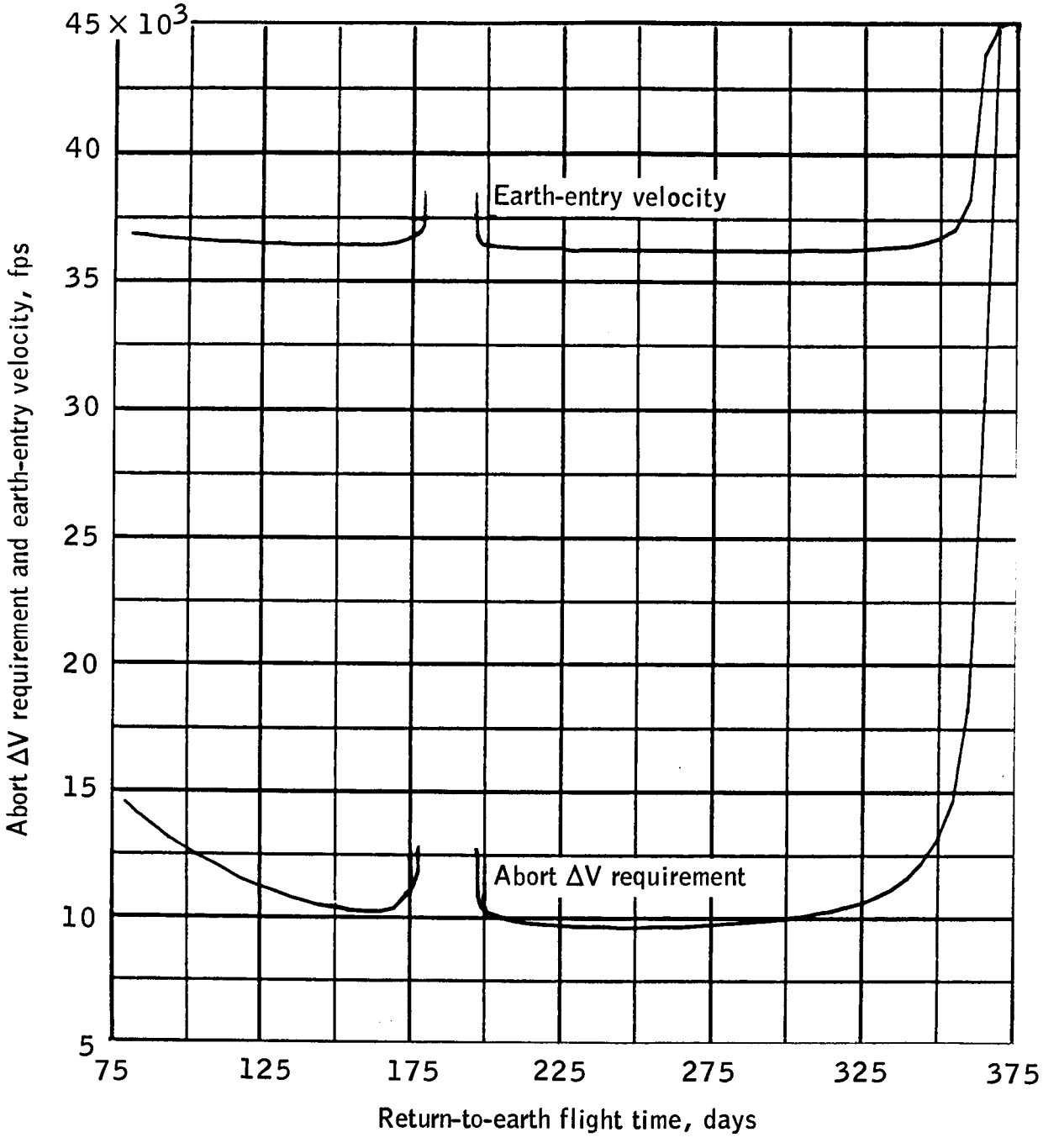

(e) Elapsed time to abort is 25 days after TMI.

Figure 6.- Continued.



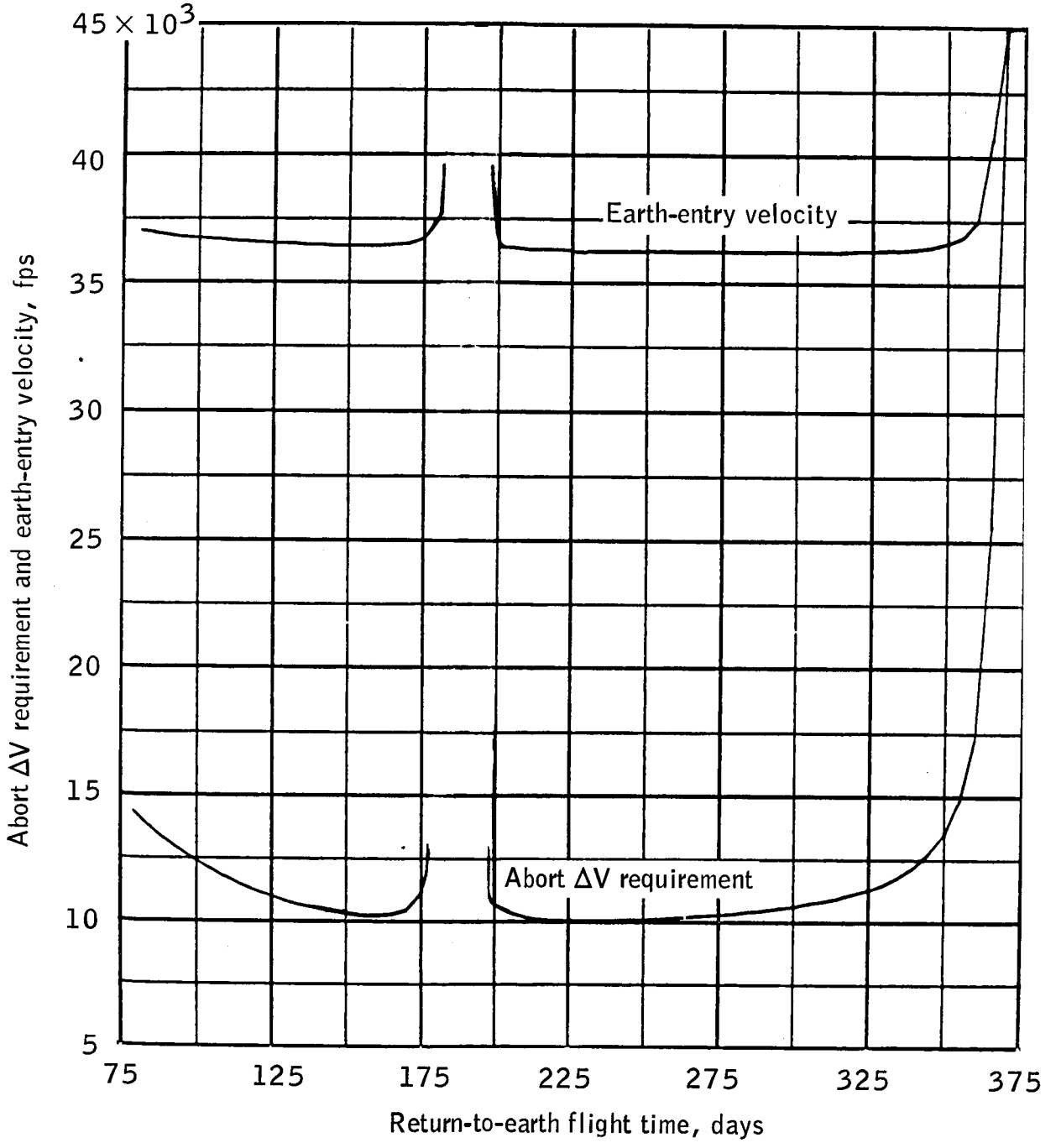

(f) Elapsed time to abort is 30 days after TMI.

Figure 6.- Continued.



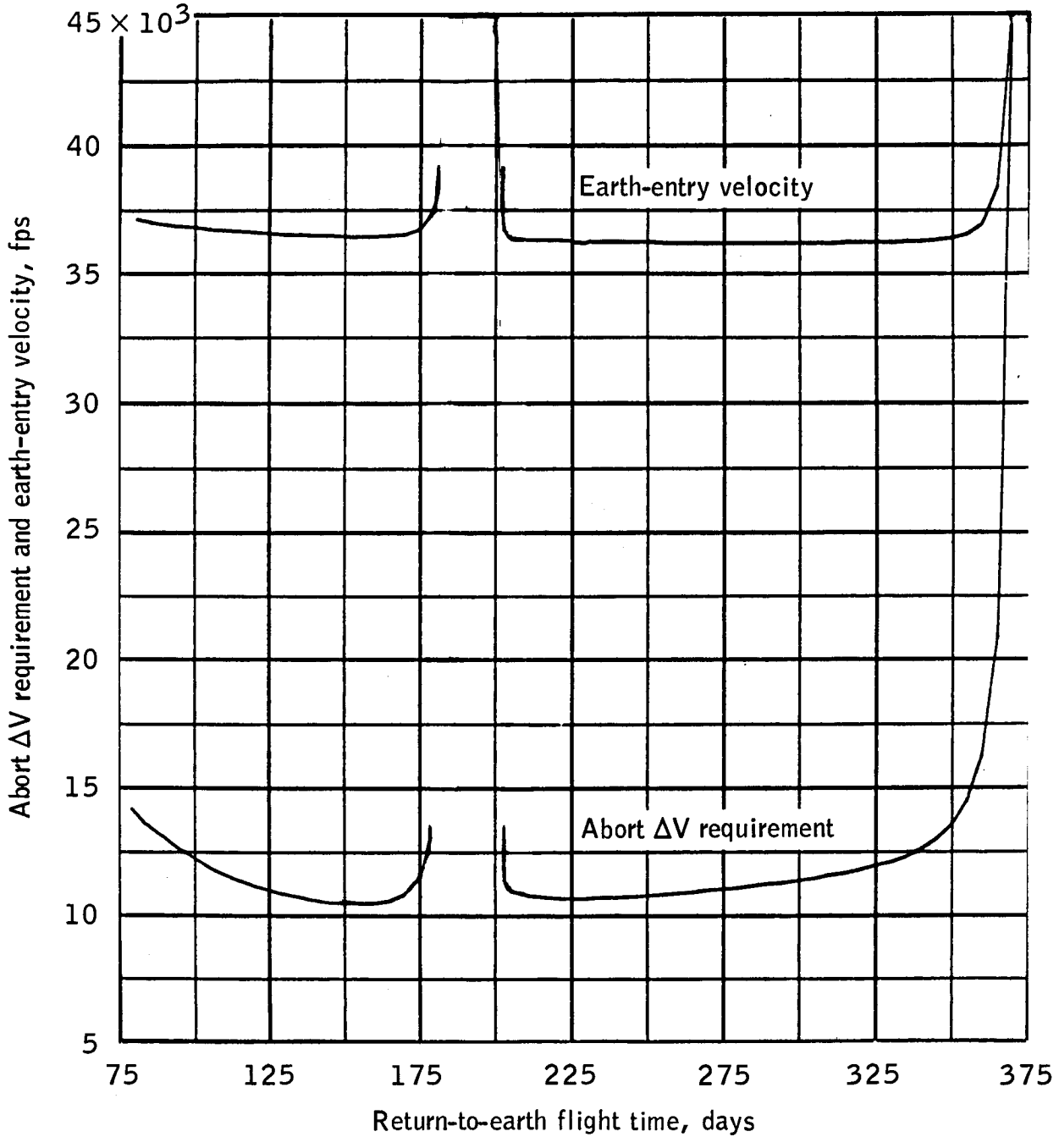

(g) Elapsed time to abort is 35 days after TMI.

Figure 6.- Continued.



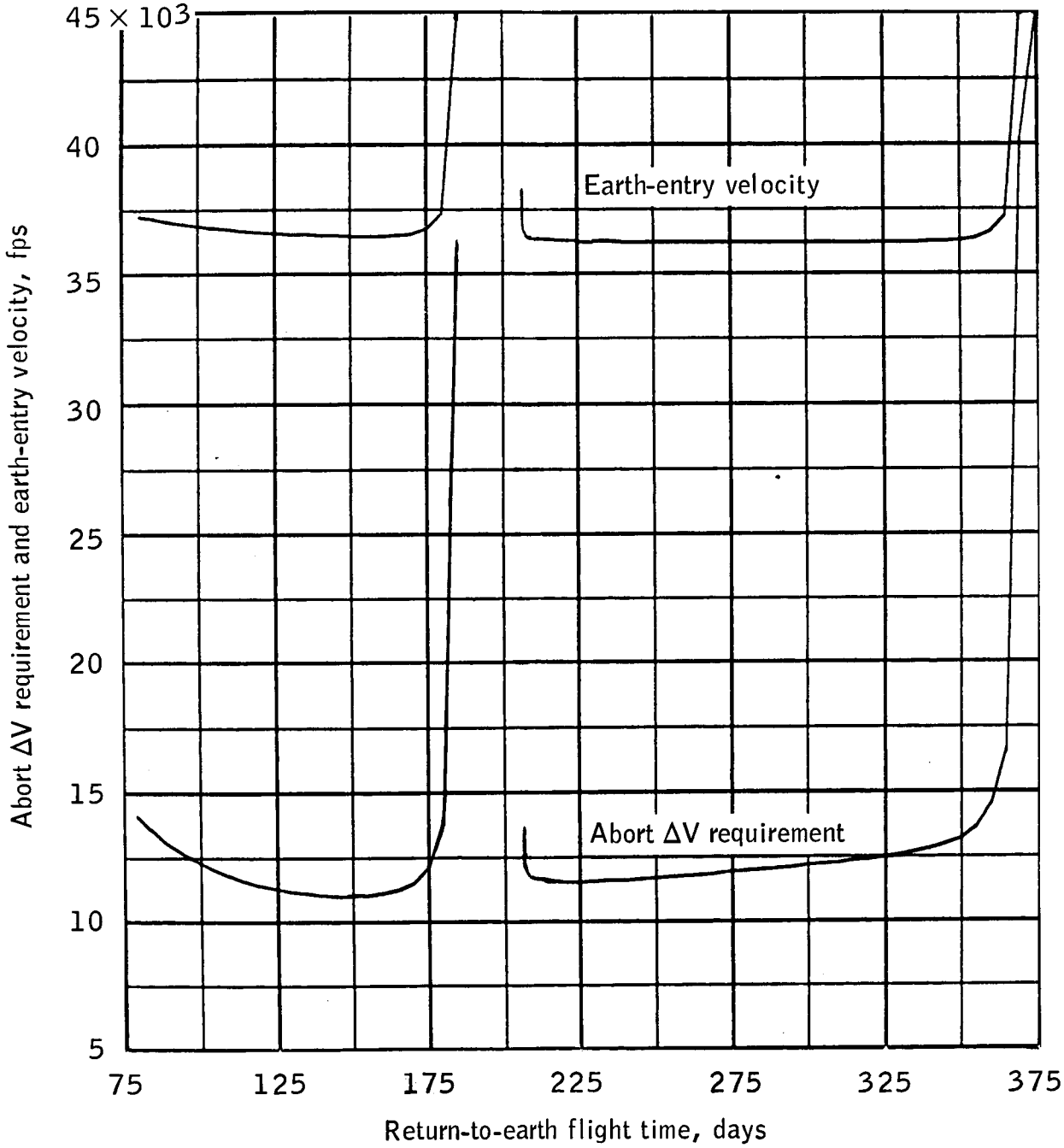

(h) Elapsed time to abort is 40 days after TMI.

Figure 6.- Continued.



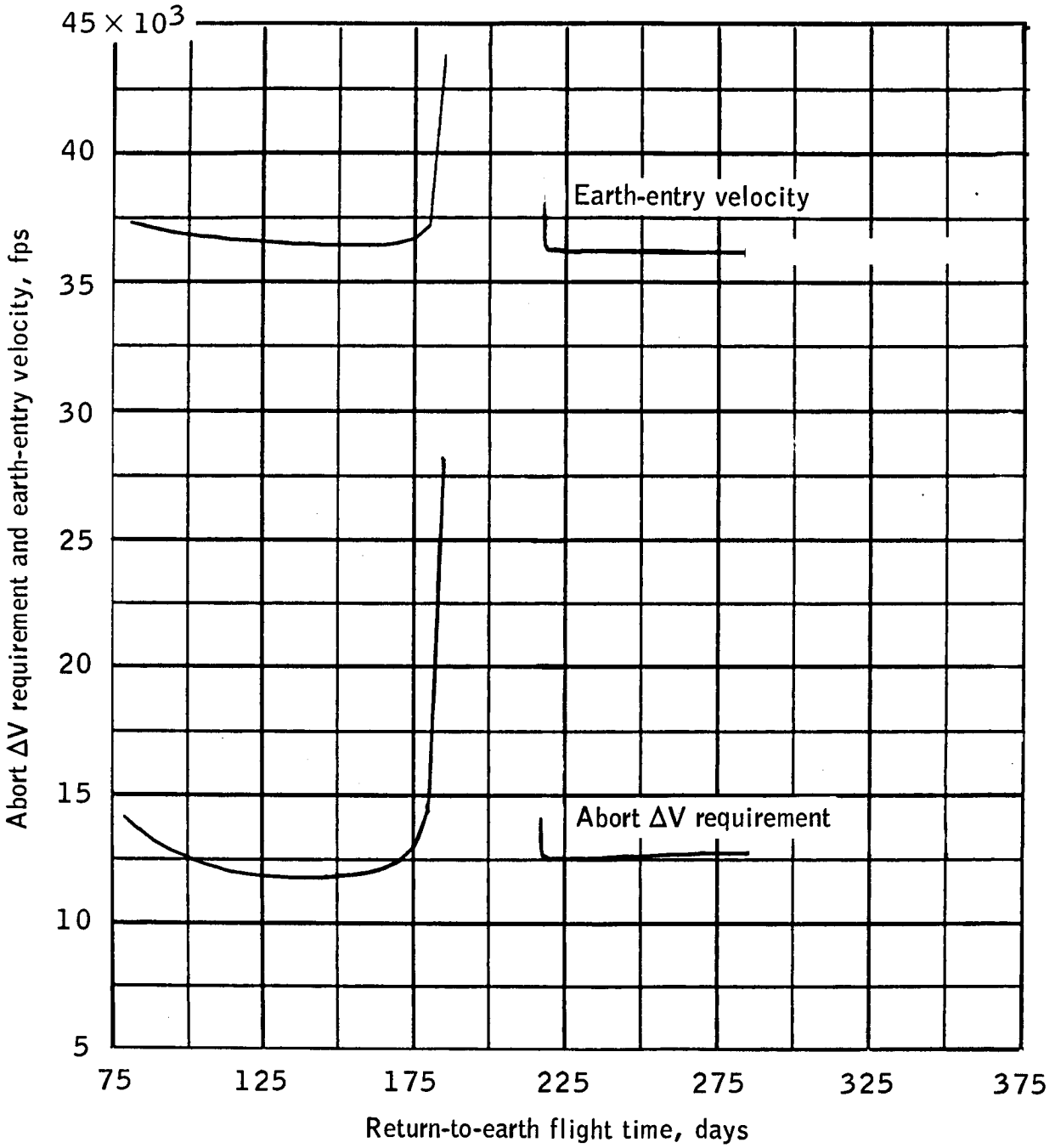

(i) Elapsed time to abort is 45 days after TMI.

Figure 6.- Continued.



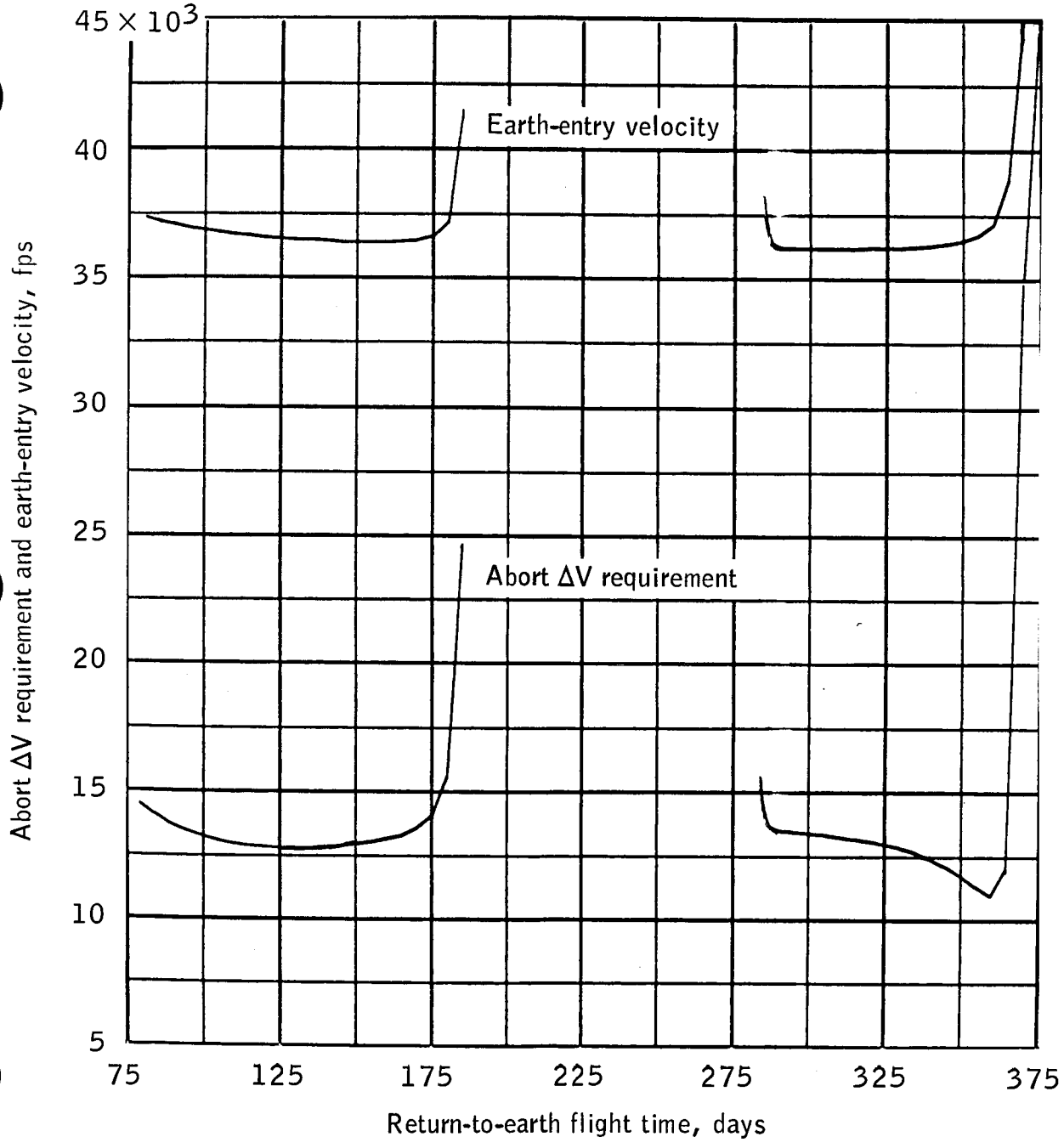

(j) Elapsed time to abort is 50 days after TMI.

Figure 6.- Continued.



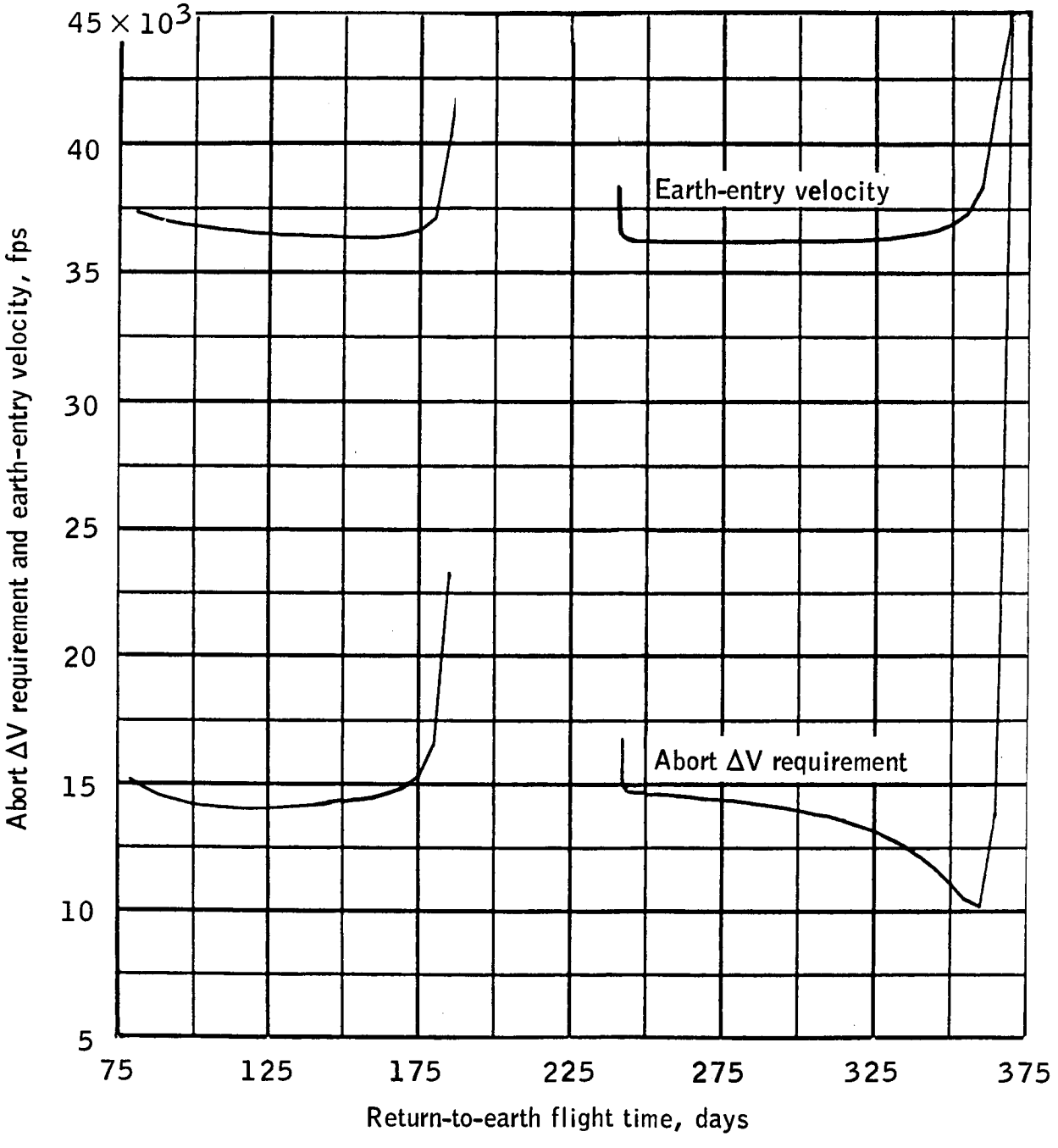

(k) Elapsed time to abort is 55 days after TMI.

Figure 6.- Continued.



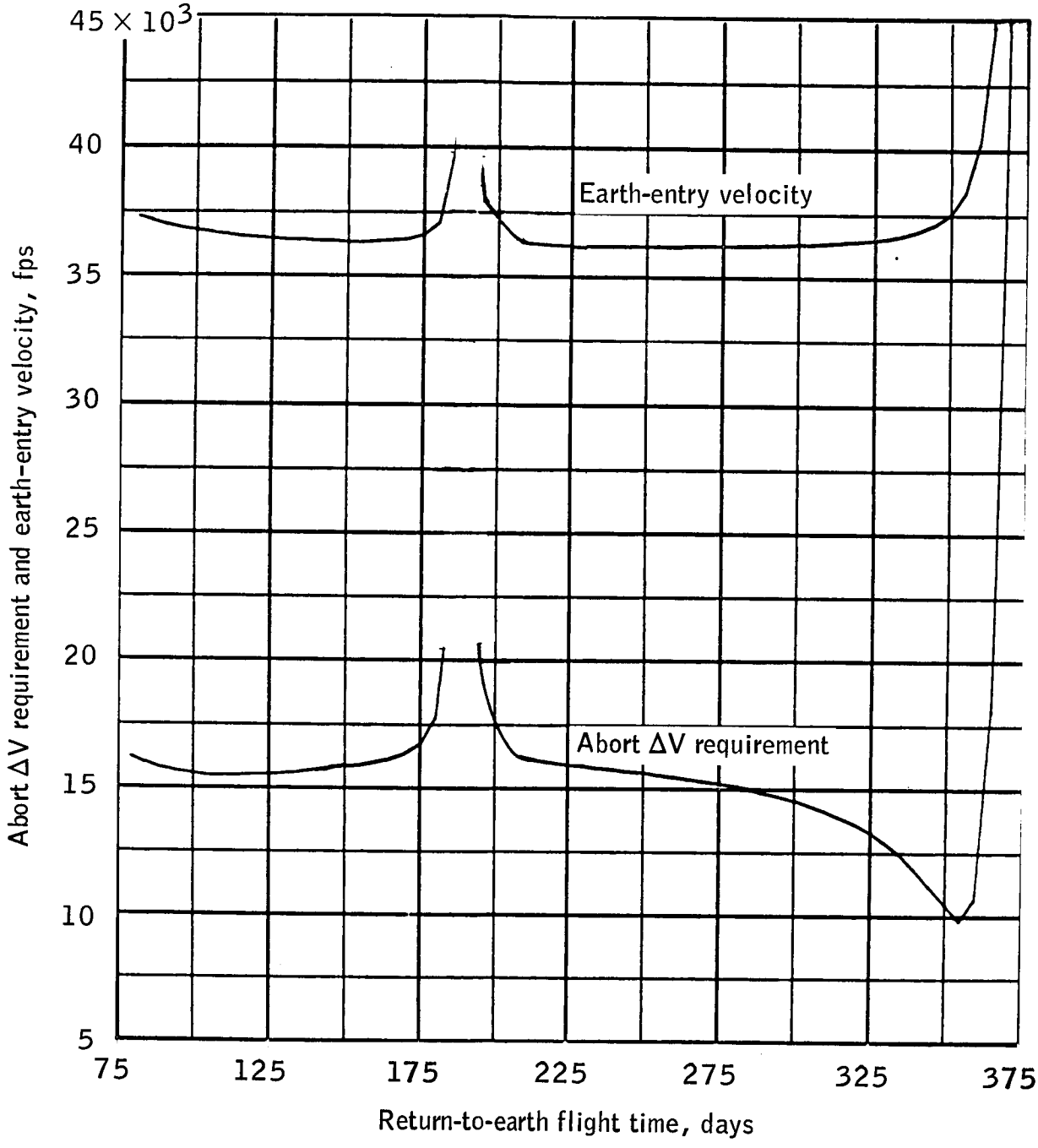

(l) Elapsed time to abort is 60 days after TMI.

Figure 6.- Continued.



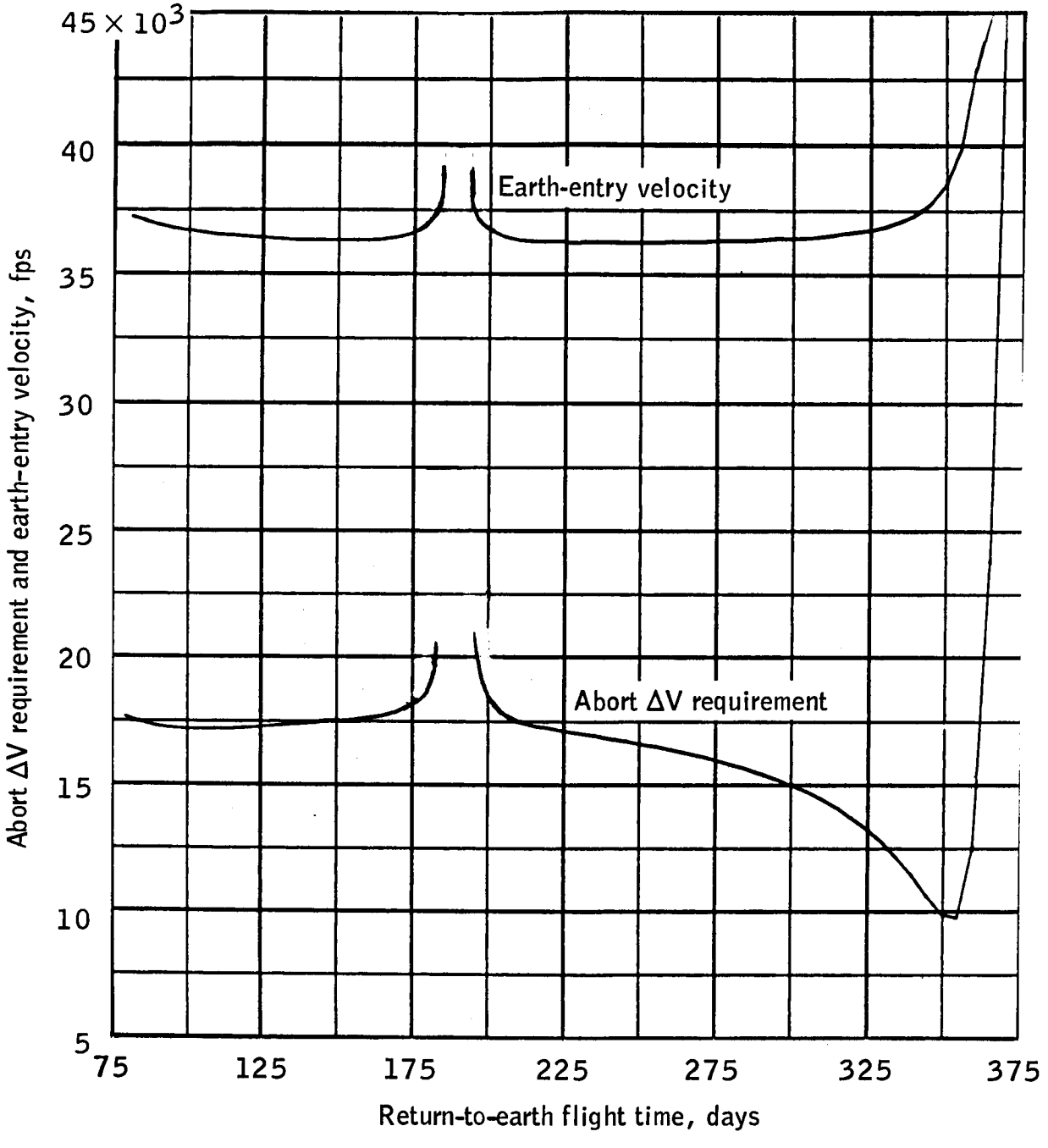

(m) Elapsed time to abort is 65 days after TMI.

Figure 6.- Continued.



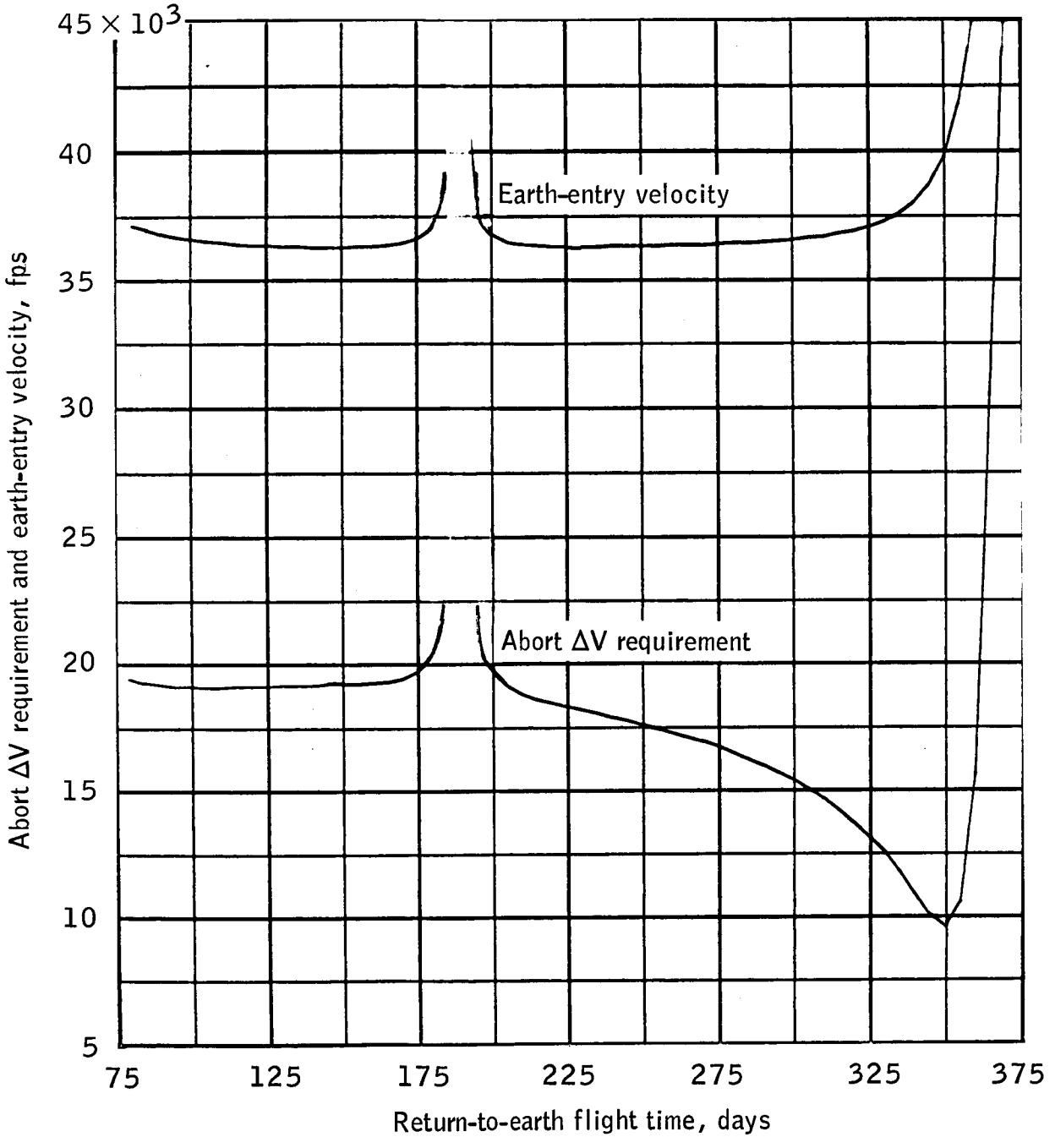

(n) Elapsed time to abort is 70 days after TMI.

Figure 6.- Continued.



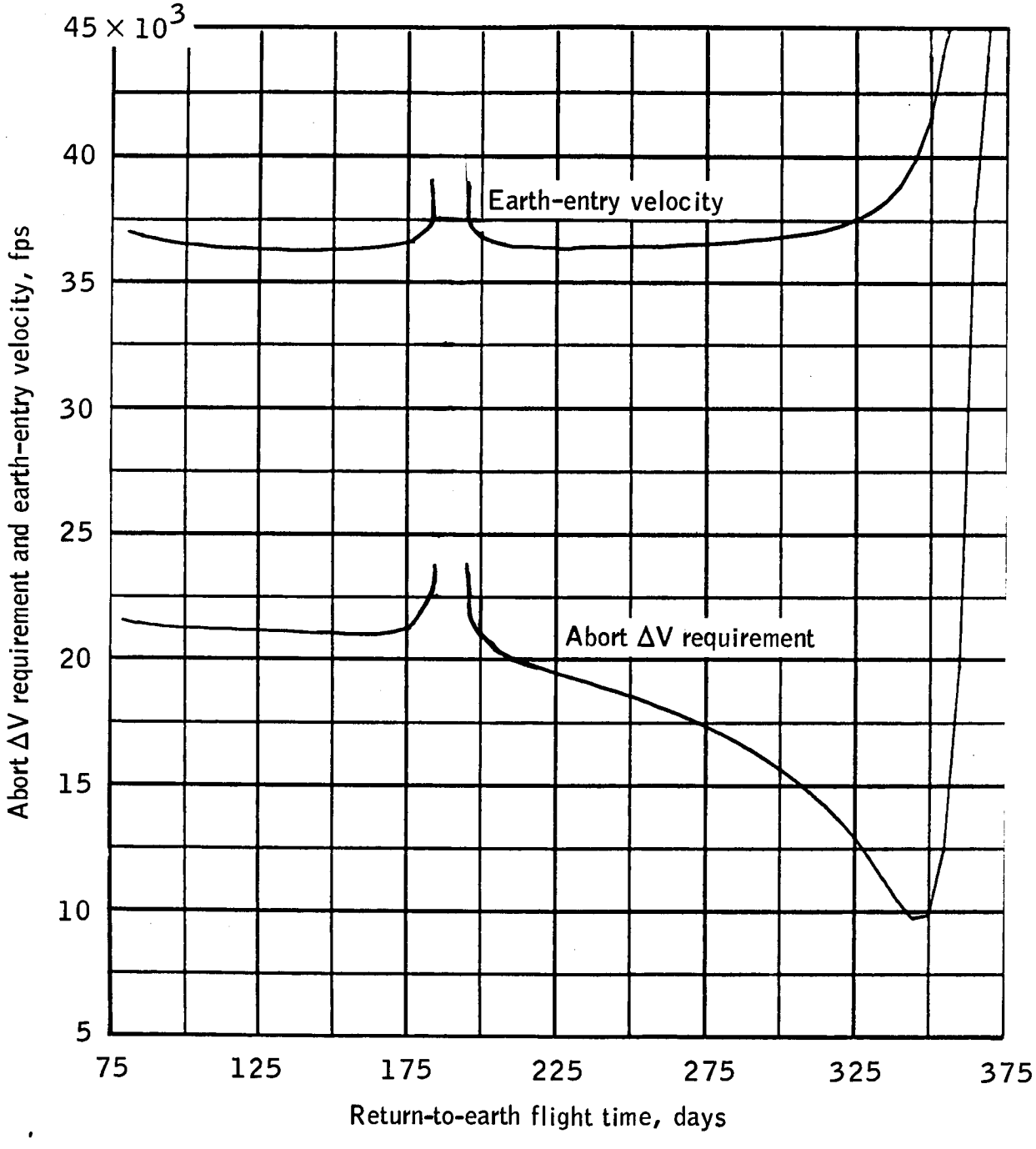

(o) Elapsed time to abort is 75 days after TMI.

Figure 6.- Continued.



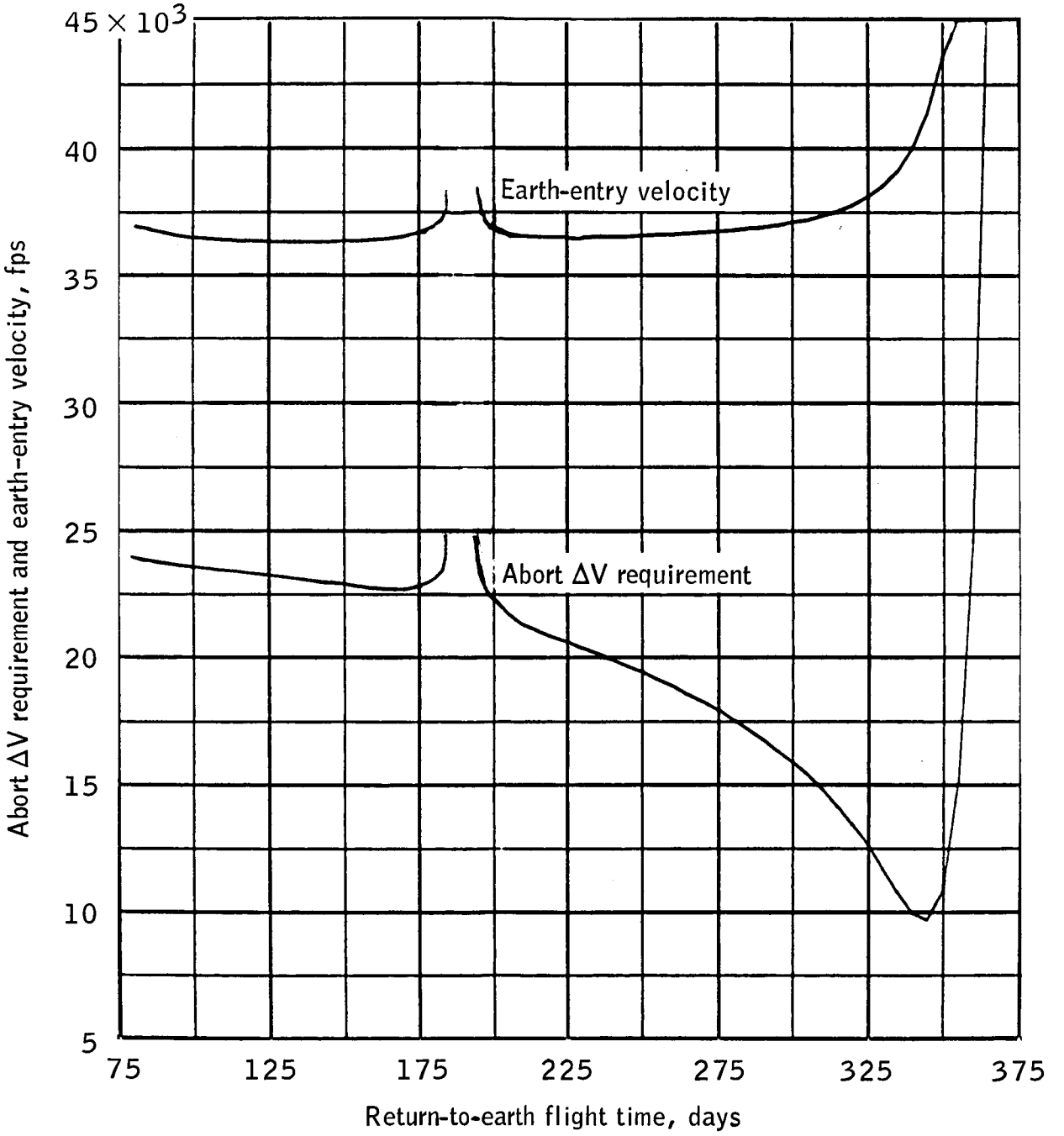

(p) Elapsed time to abort is 80 days after TMI.

Figure 6.- Continued.



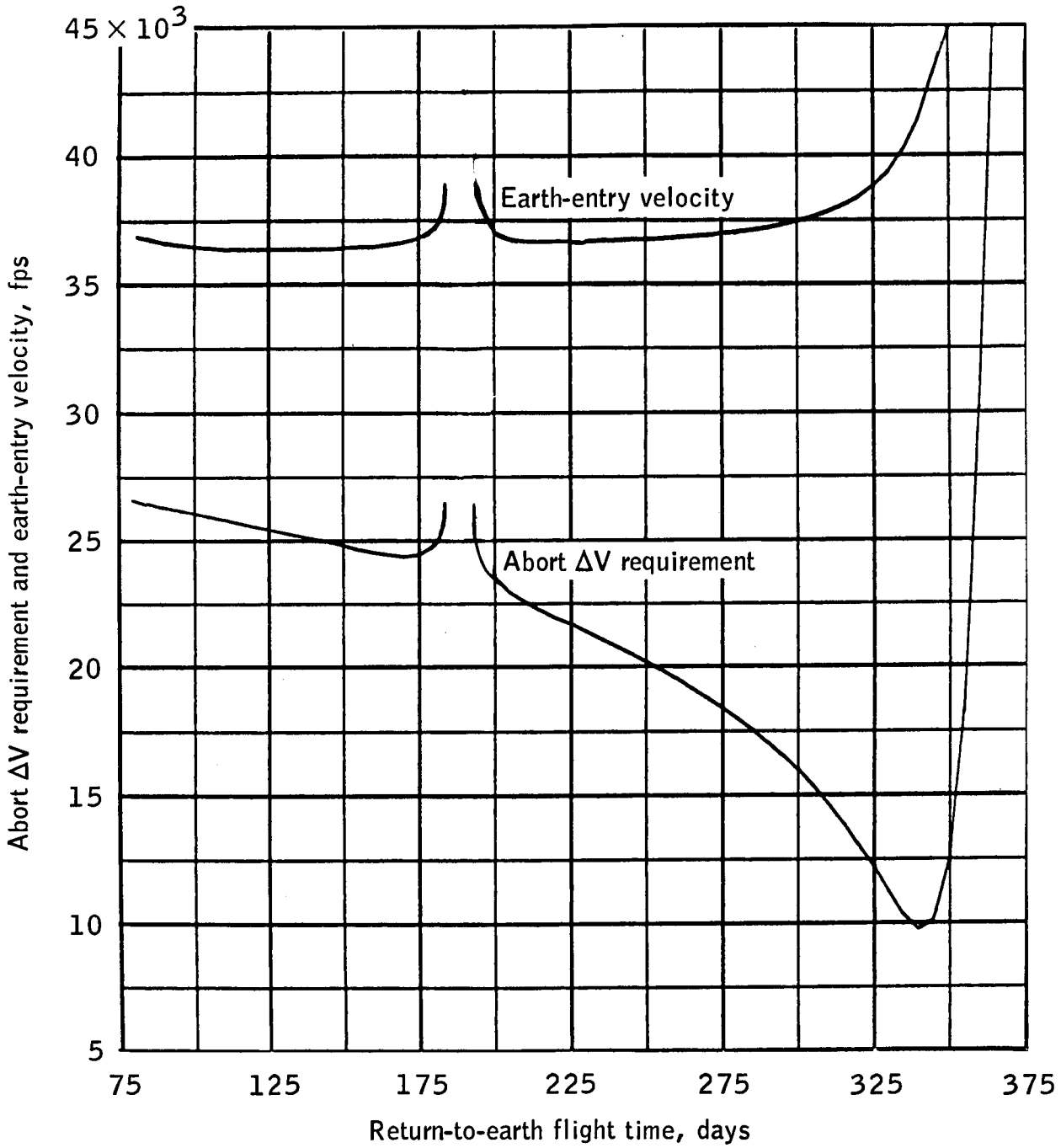

(q) Elapsed time to abort is 85 days after TMI.

Figure 6.- Continued.



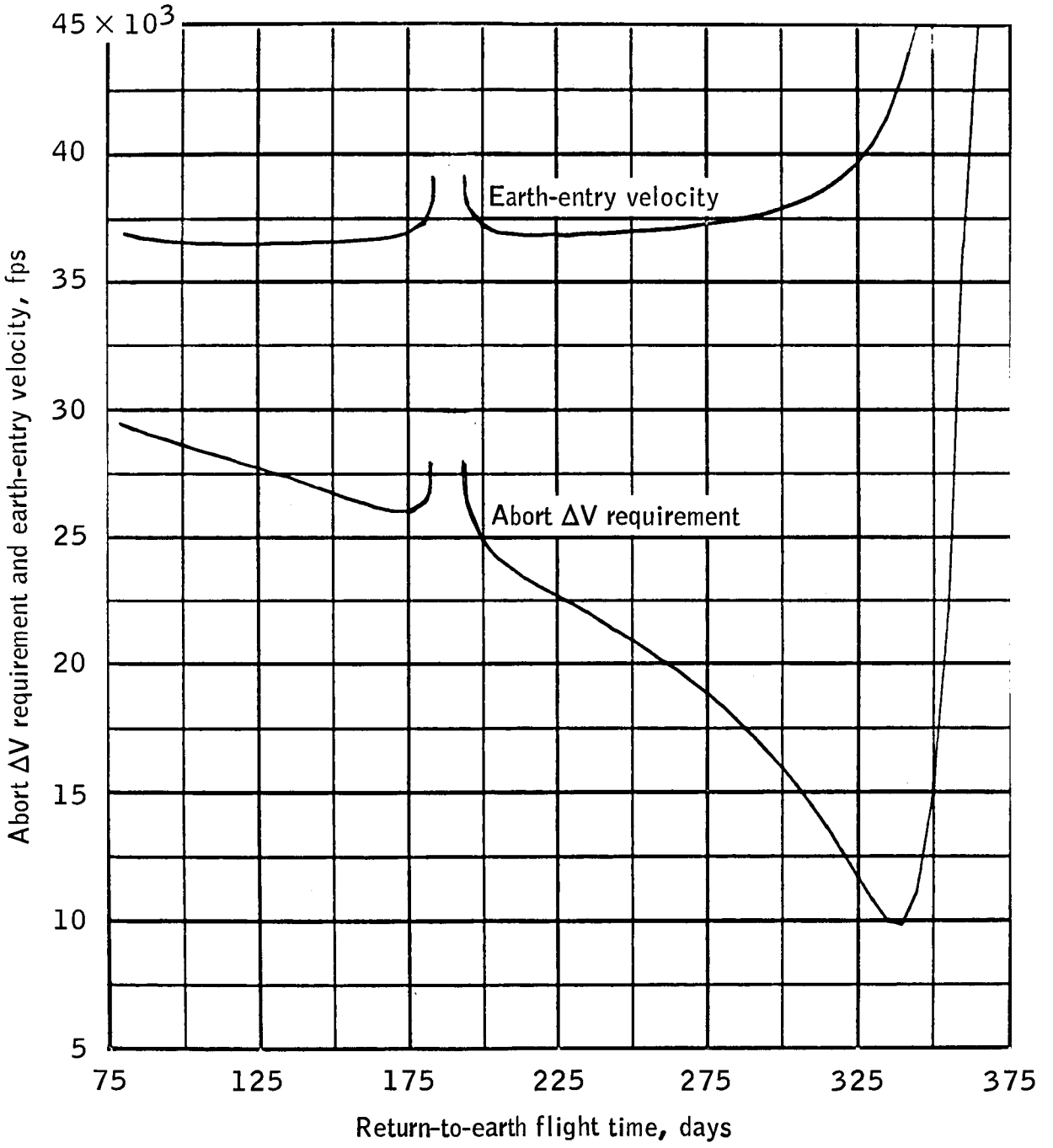

(r) Elapsed time to abort is 90 days after TMI.

Figure 6.- Continued.



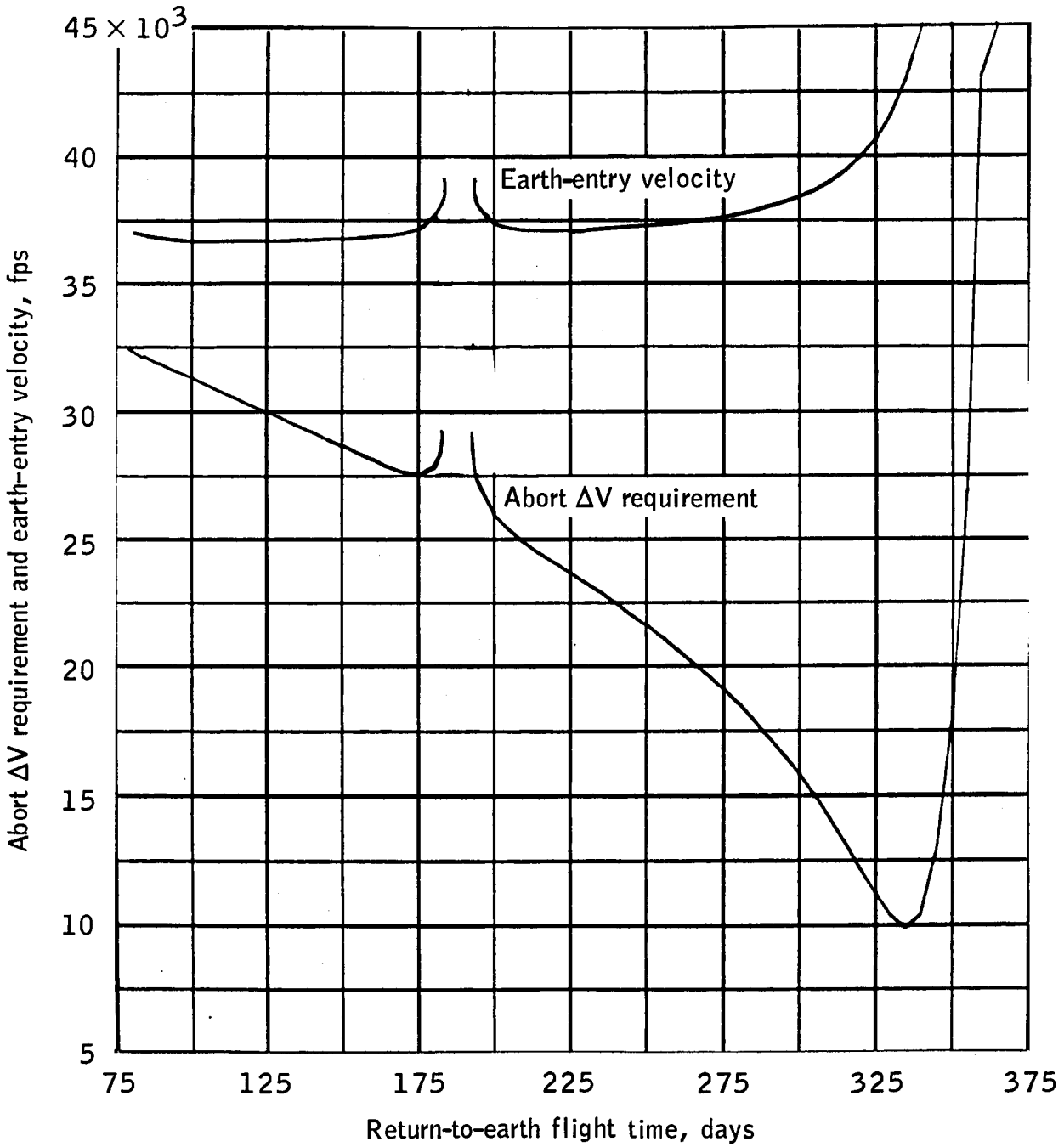

(s) Elapsed time to abort is 95 days after TMI.

Figure 6.- Continued.



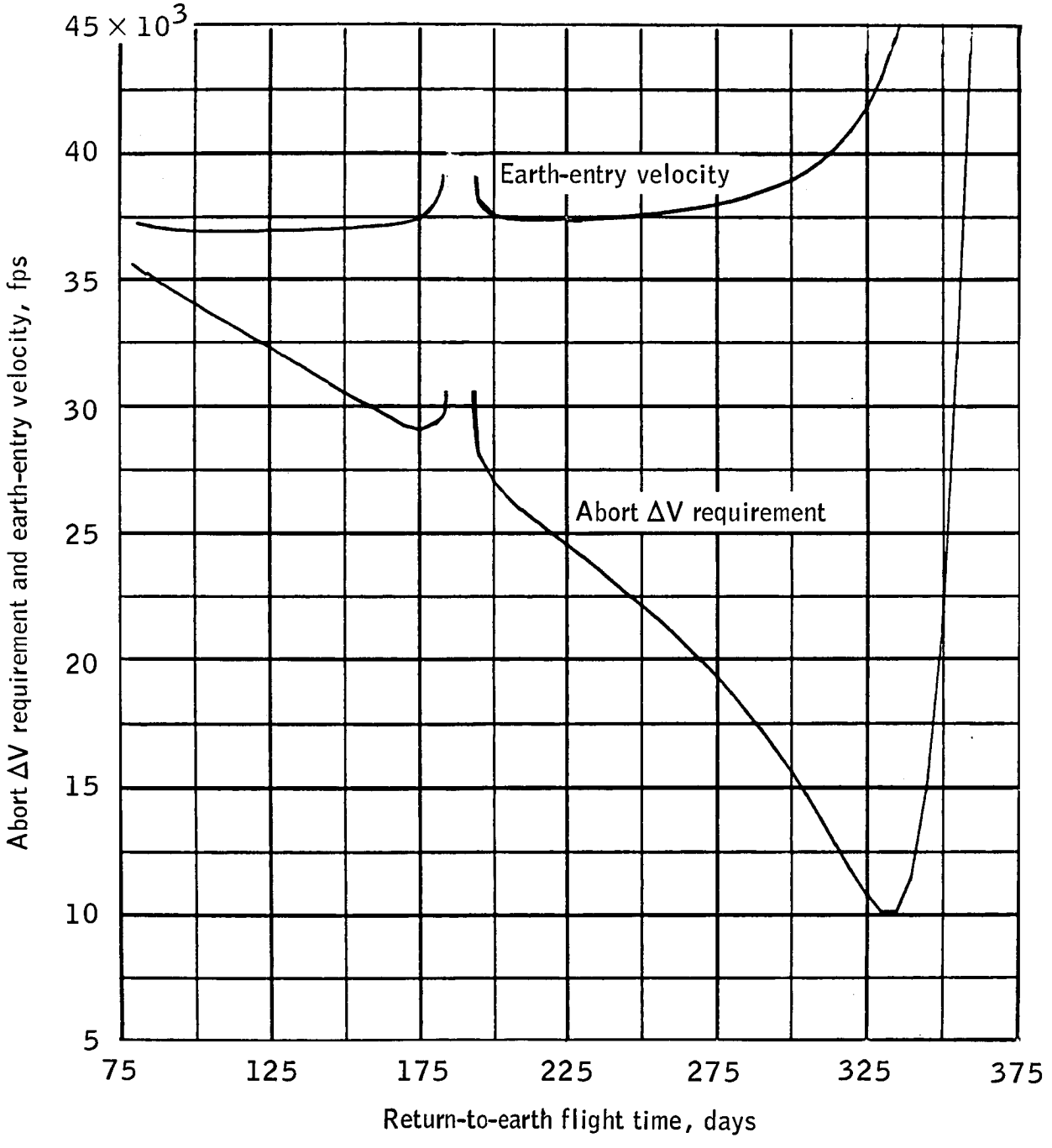

(t) Elapsed time to abort is 100 days after TMI.

Figure 6.- Continued.



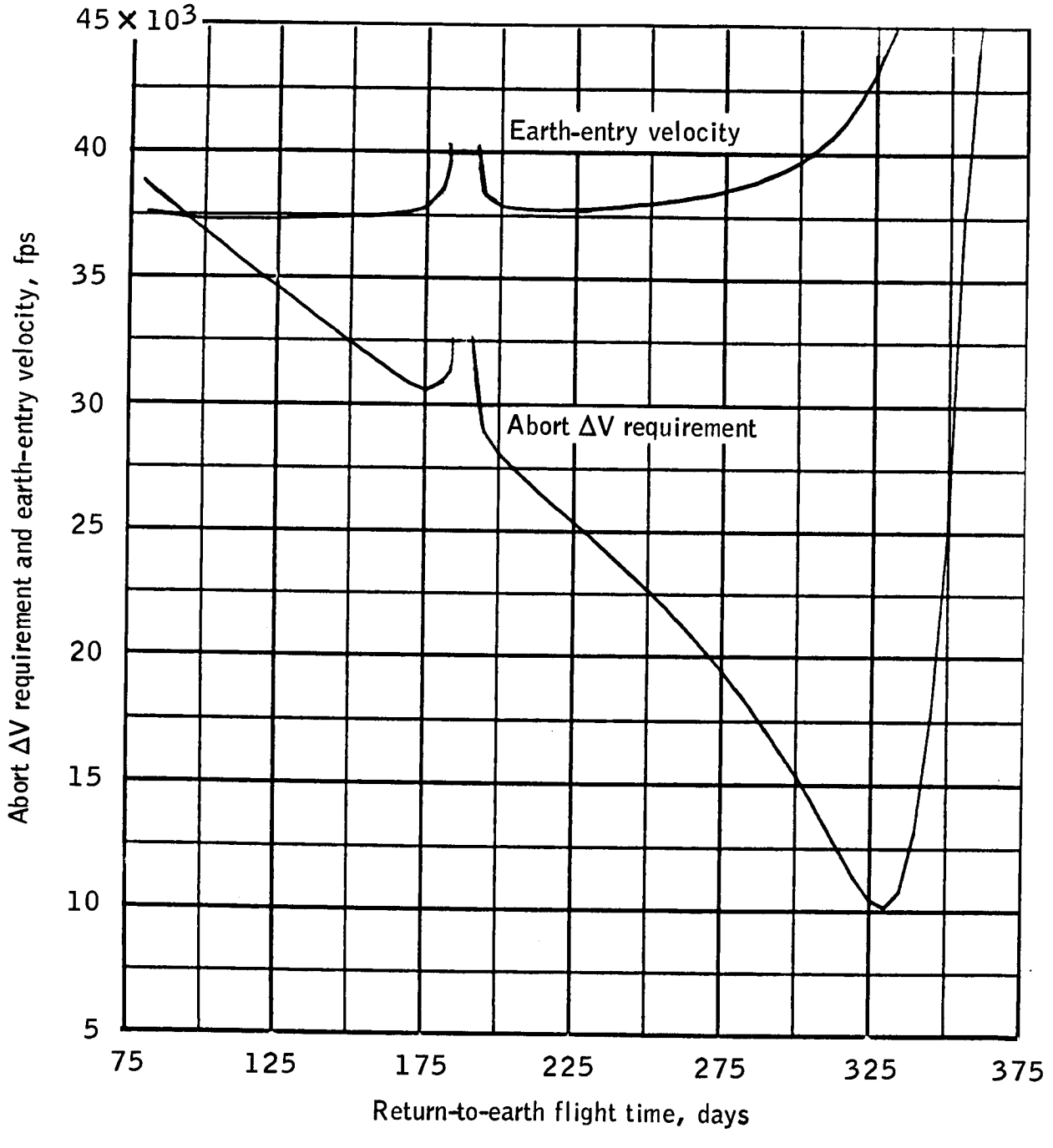

(u) Elapsed time to abort is 105 days after TMI.

Figure 6.- Continued.



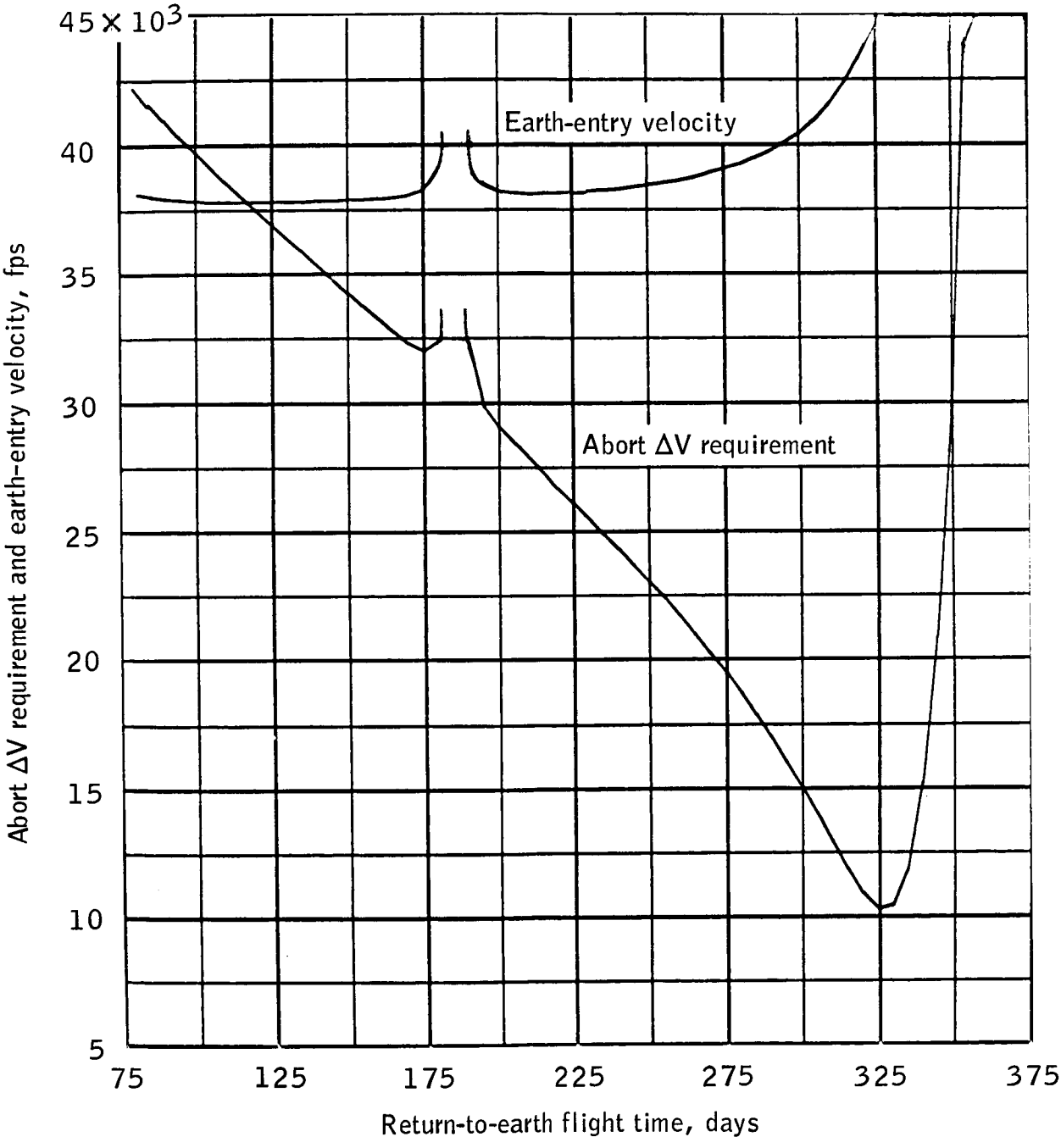

(v) Elapsed time to abort is 110 days after TMI.

Figure 6.- Continued.



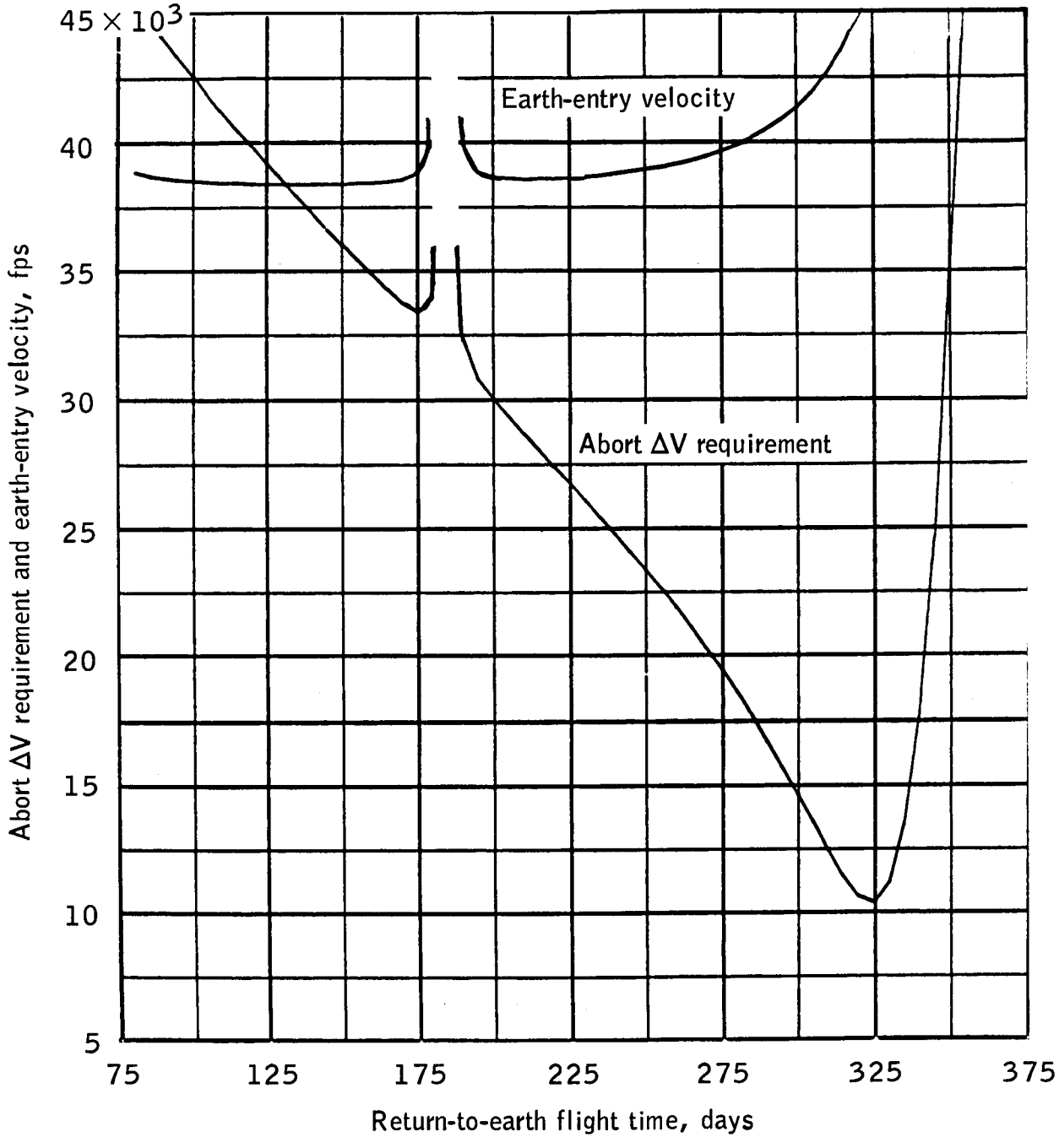

(w) Elapsed time to abort is 115 days after TMI.

Figure 6.- Continued.



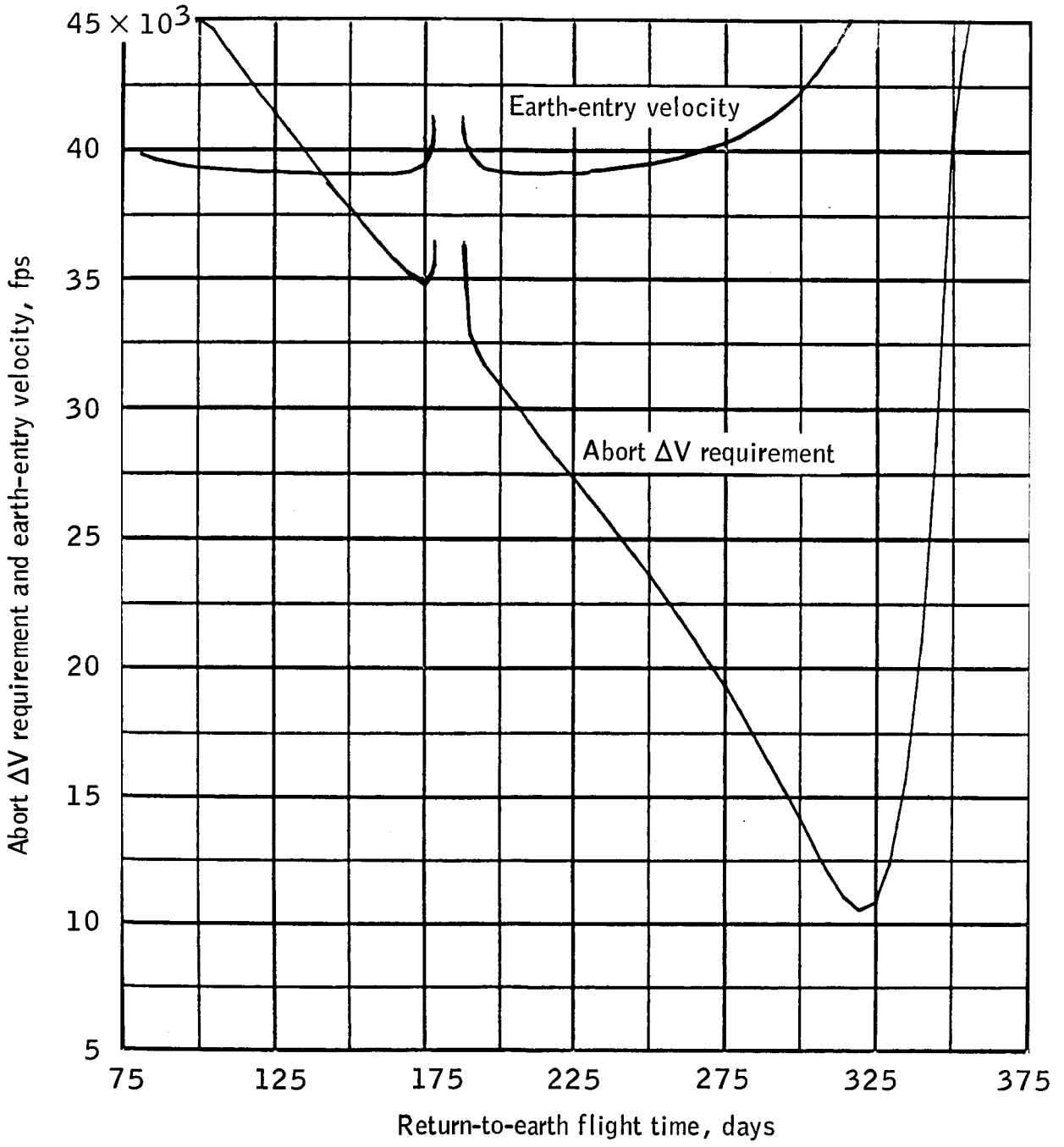

(x) Elapsed time to abort is 120 days after TMI.

Figure 6.- Continued.



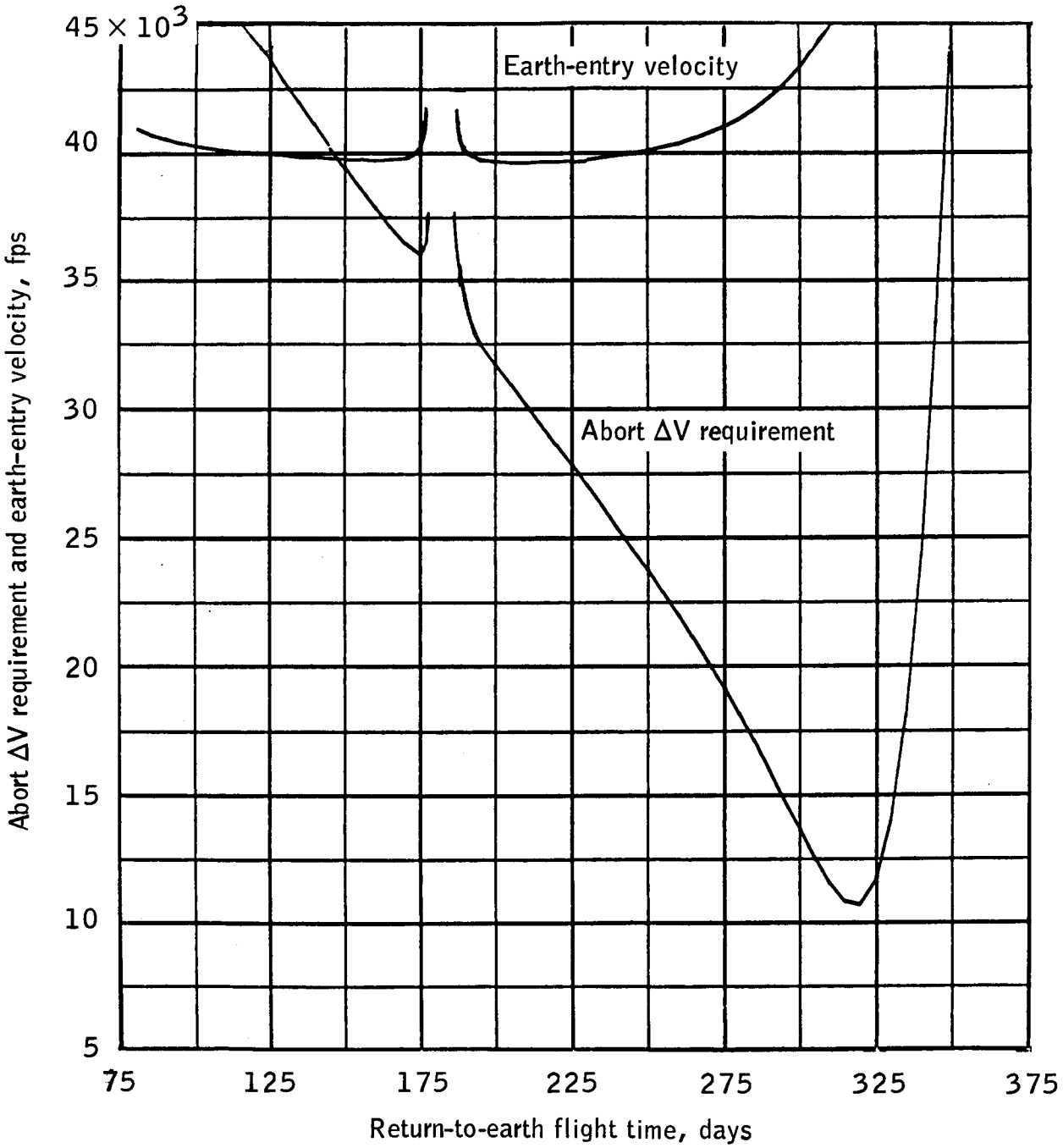

(y) Elapsed time to abort is 125 days after TMI.

Figure 6.- Continued.



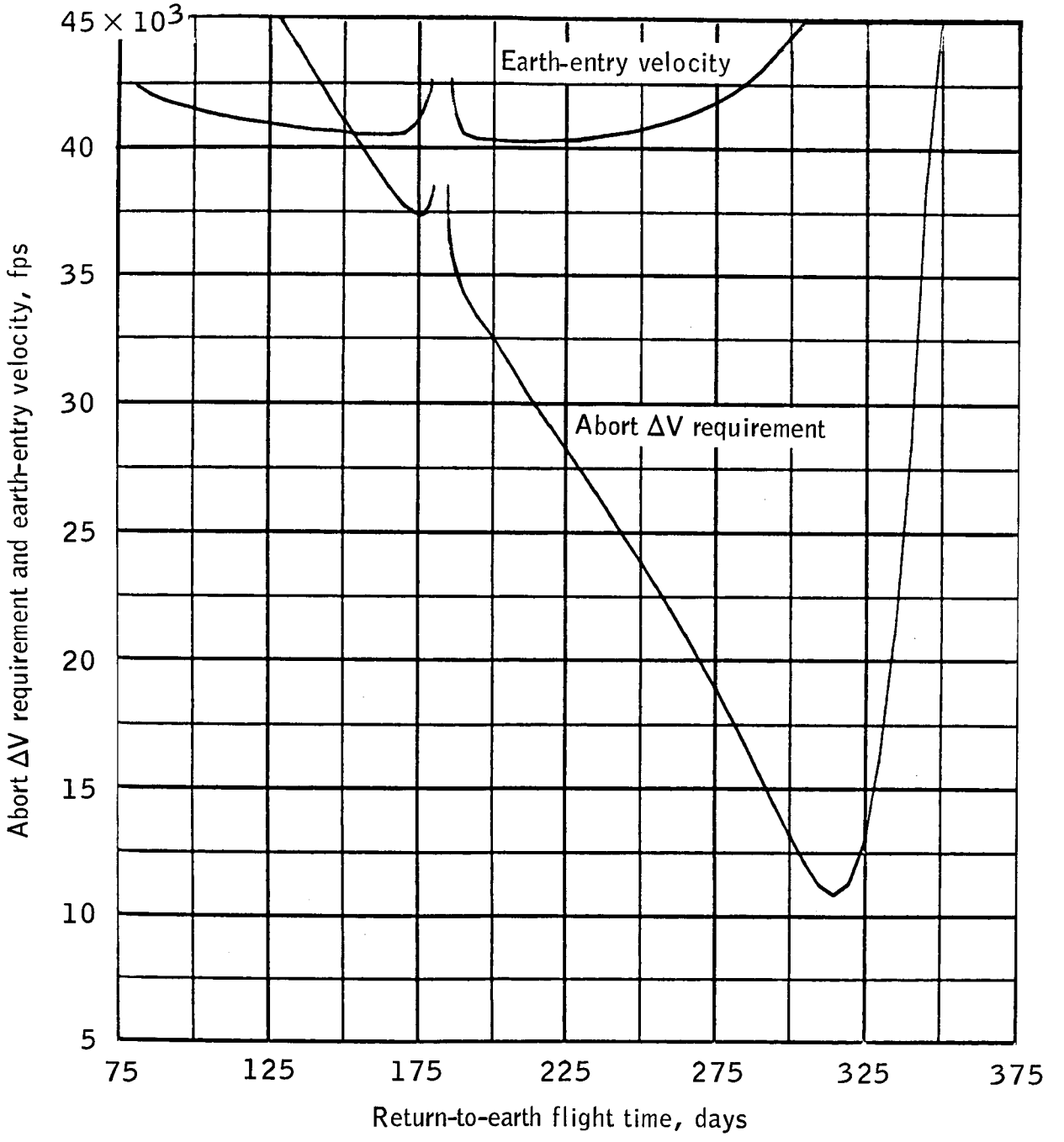

(z) Elapsed time to abort is 130 days after TMI.

Figure 6.- Continued.



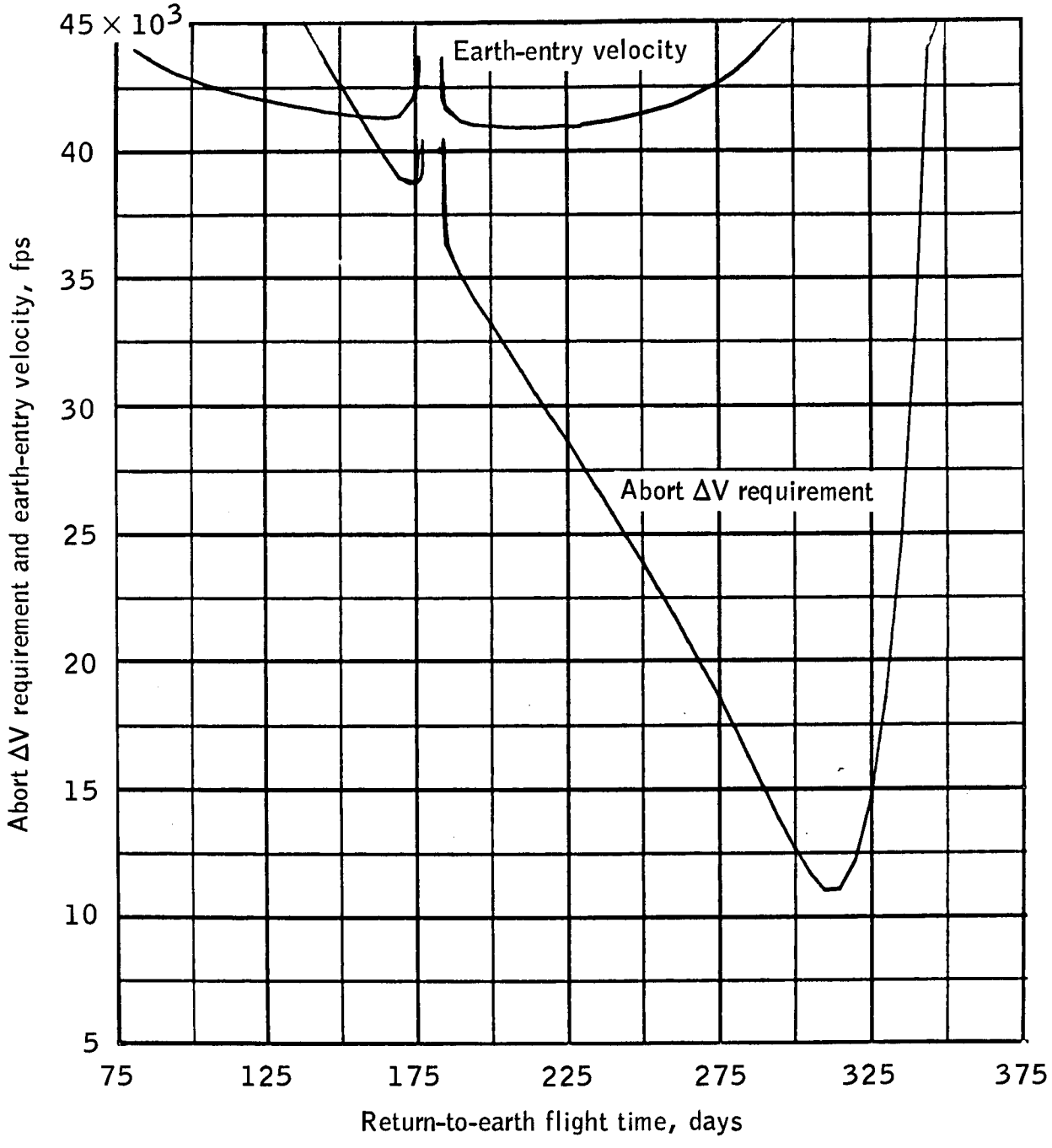

(aa) Elapsed time to abort is 135 days after TMI.

Figure 6.- Continued.



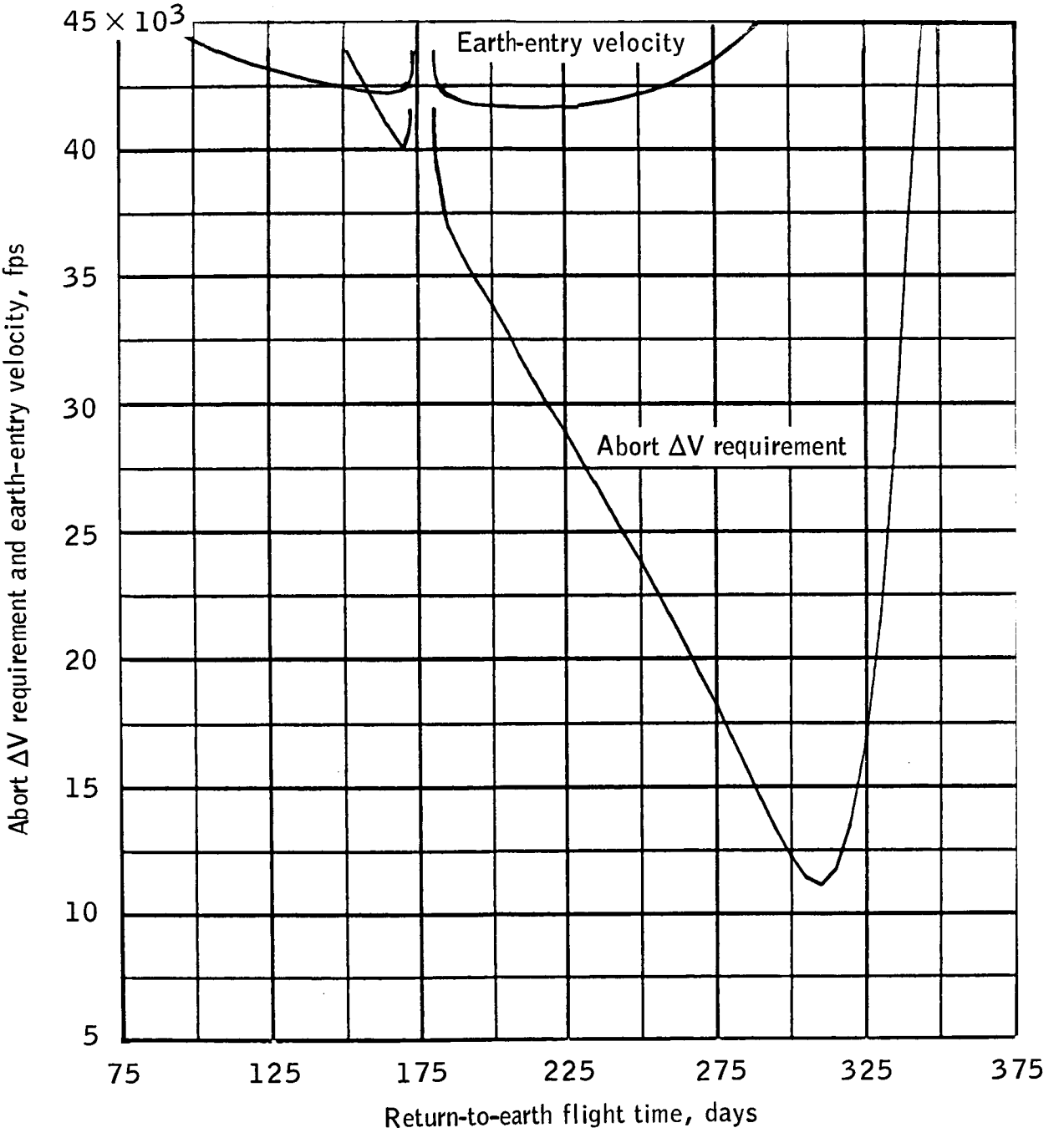

(bb) Elapsed time to abort is 140 days after TMI.

Figure 6.- Continued.



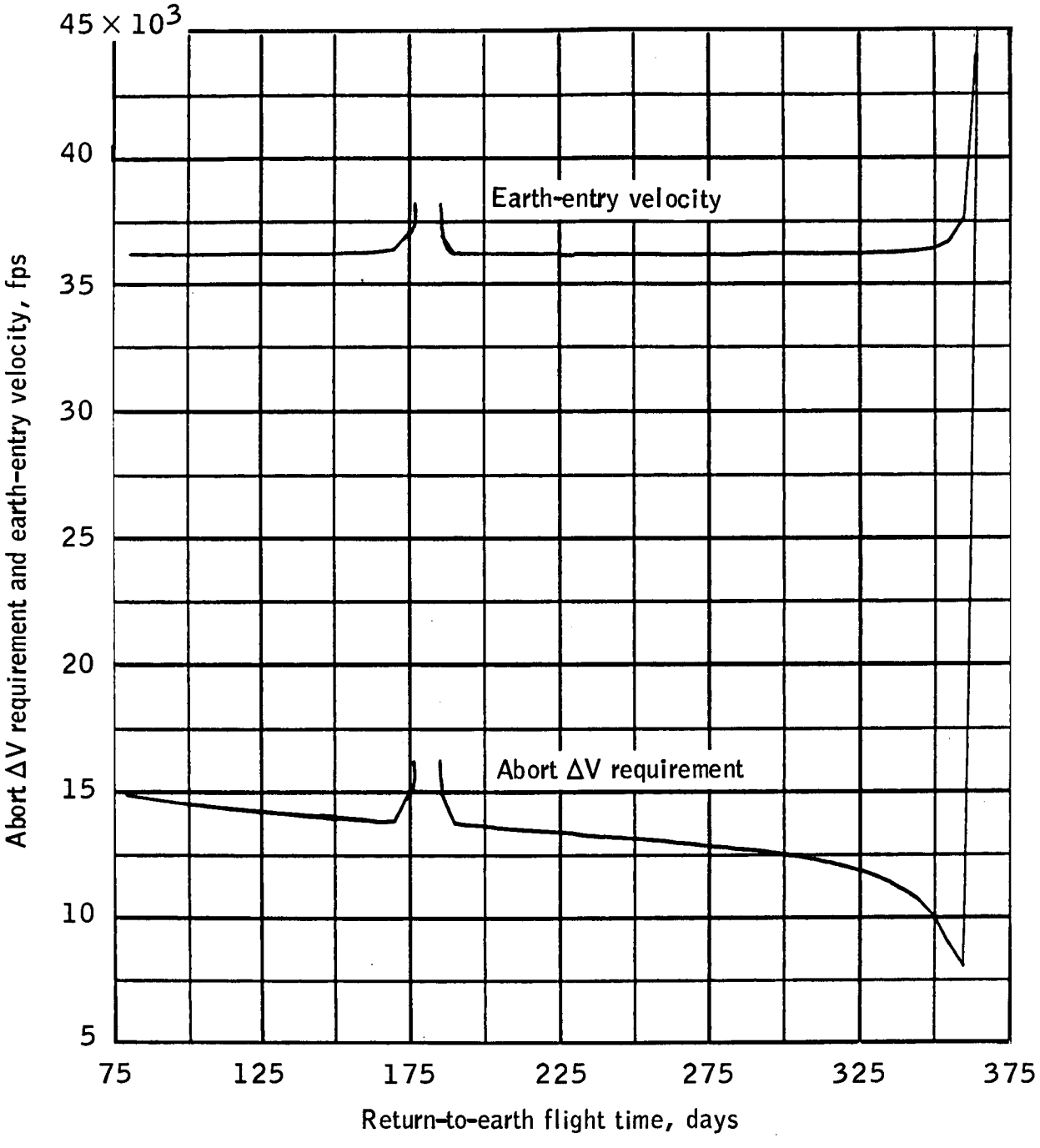

(cc) Elapsed time to abort is 145 days after TMI.

Figure 6.- Continued.



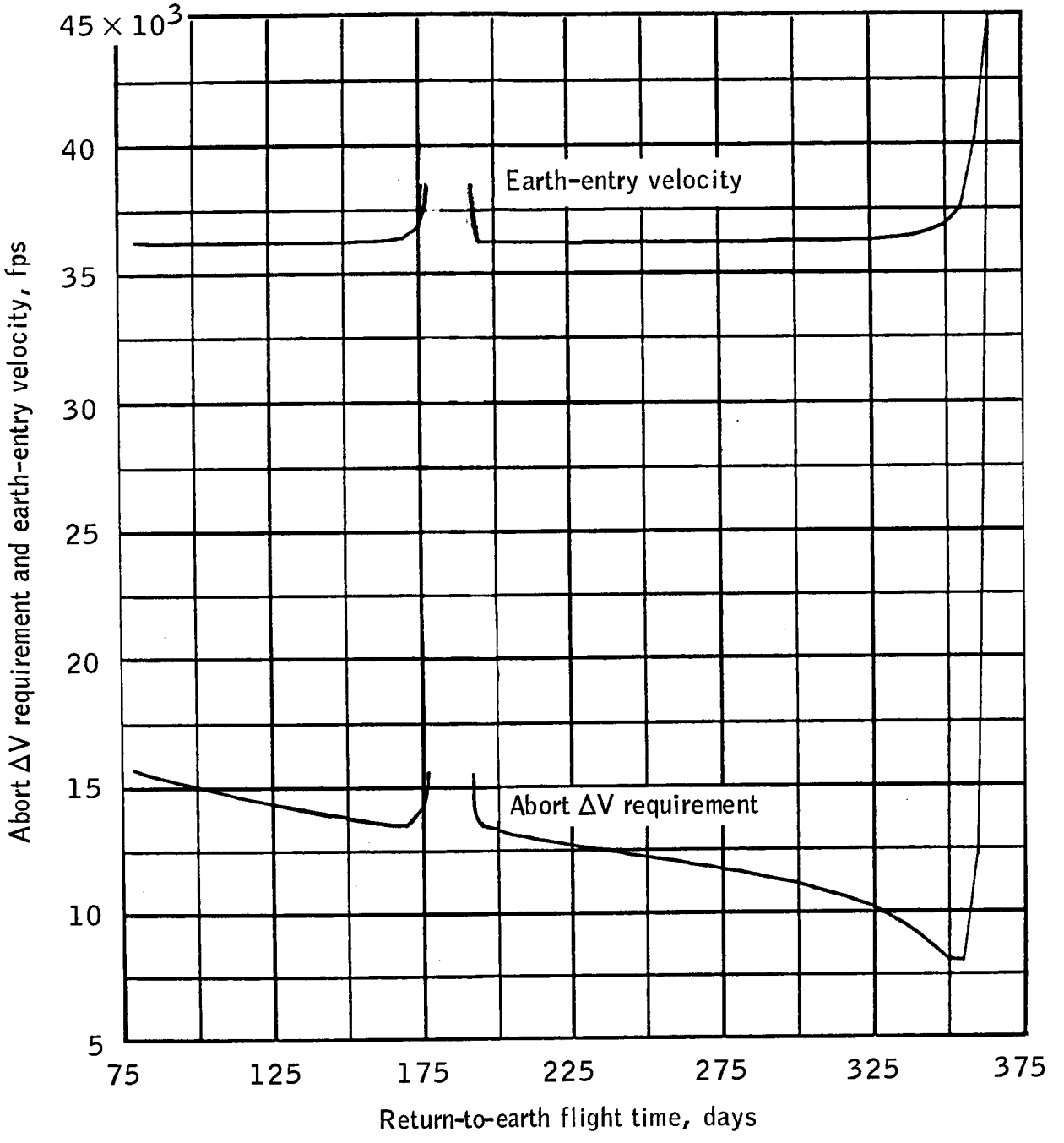

(dd) Elapsed time to abort is 150 days after TMI.

Figure 6.- Concluded.



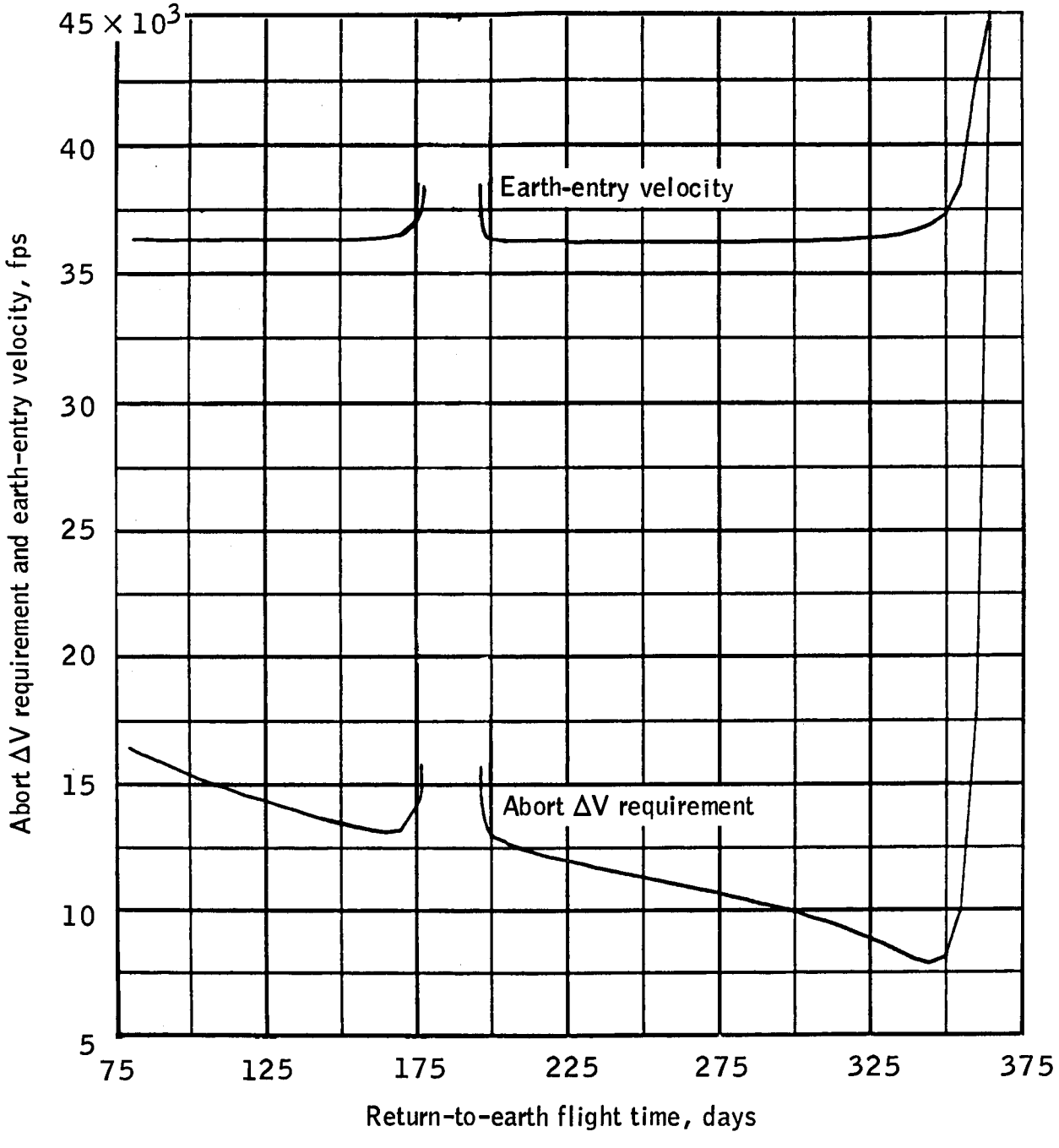

(a) Elapsed time to abort is 5 days after TMI.

Figure 7.- Velocity characteristics of heliocentric abort trajectories, 1981 Mars conjunction class mission.



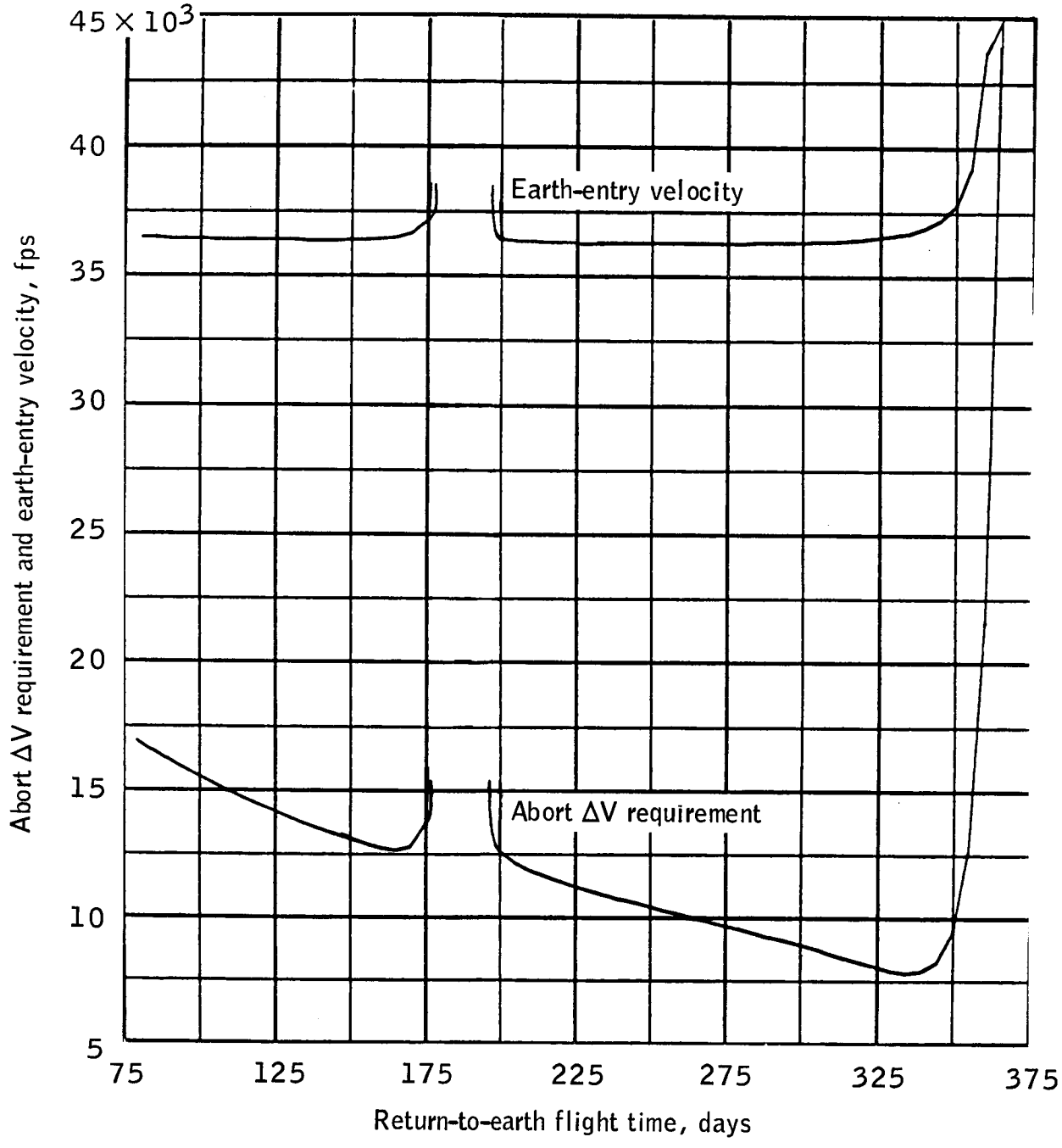

(b) Elapsed time to abort is 10 days after TMI.

Figure 7.- Continued.



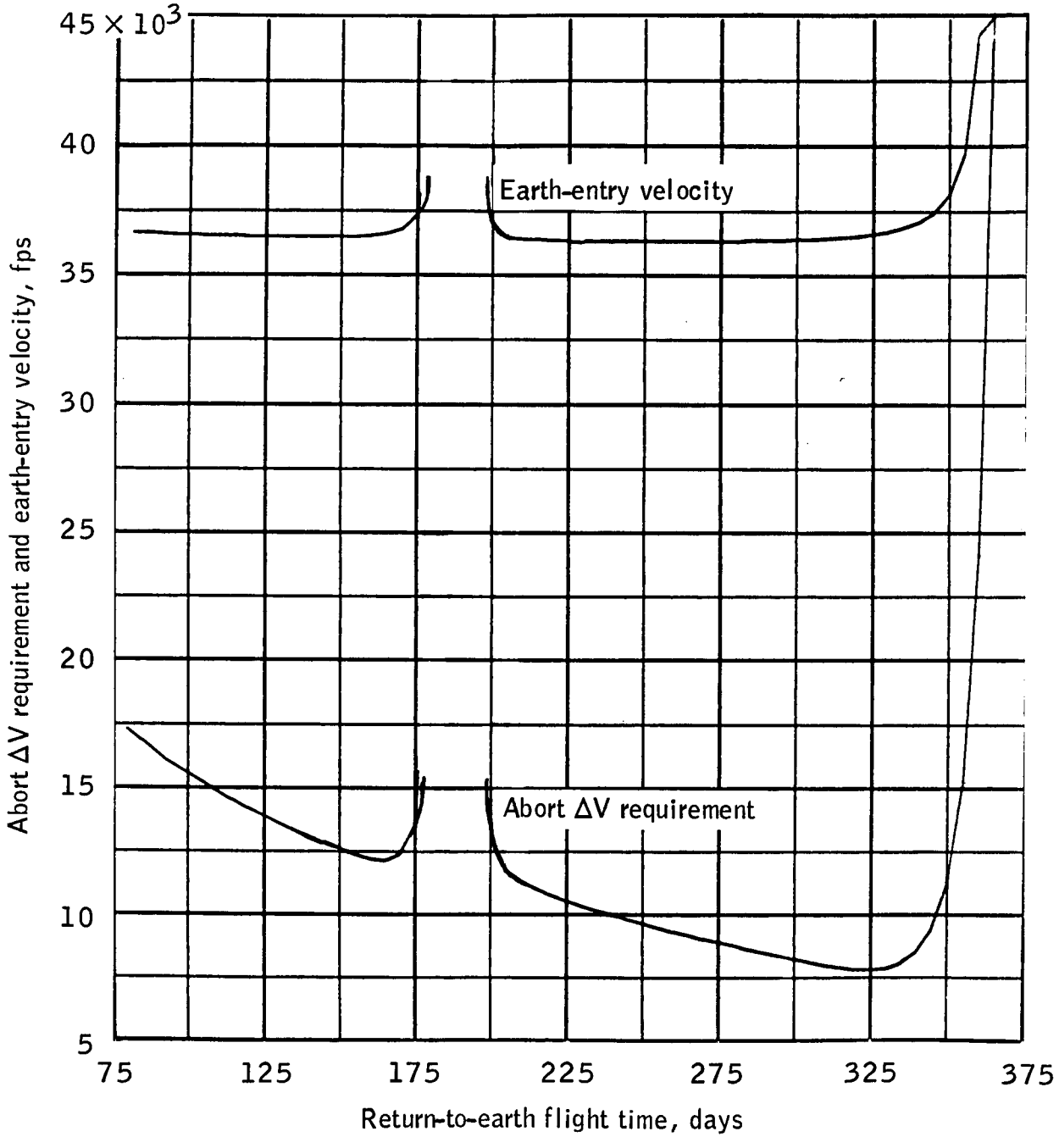

(c) Elapsed time to abort is 15 days after TMI.

Figure 7.- Continued.



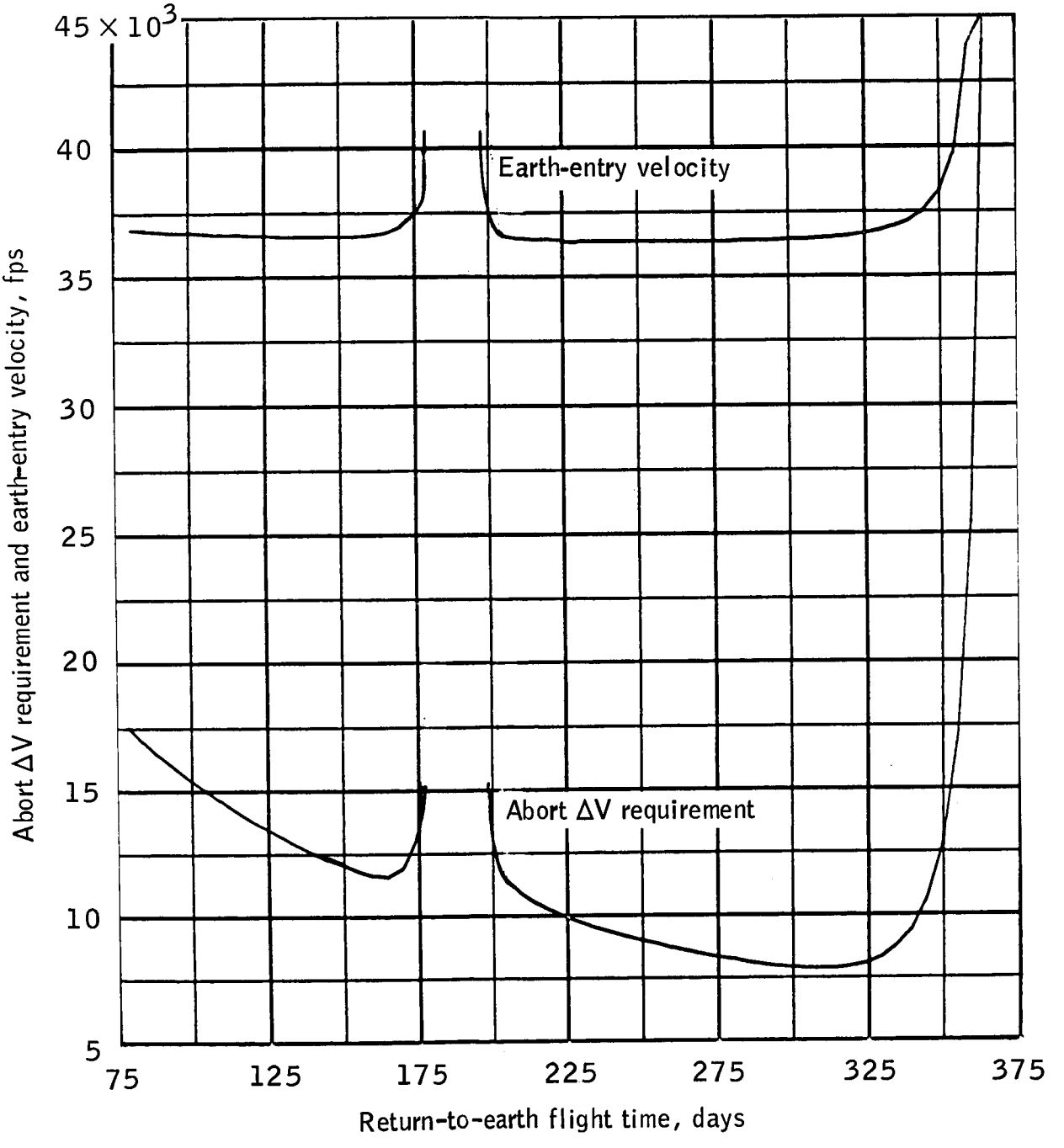

(d) Elapsed time to abort is 20 days after TMI.

Figure 7.- Continued.



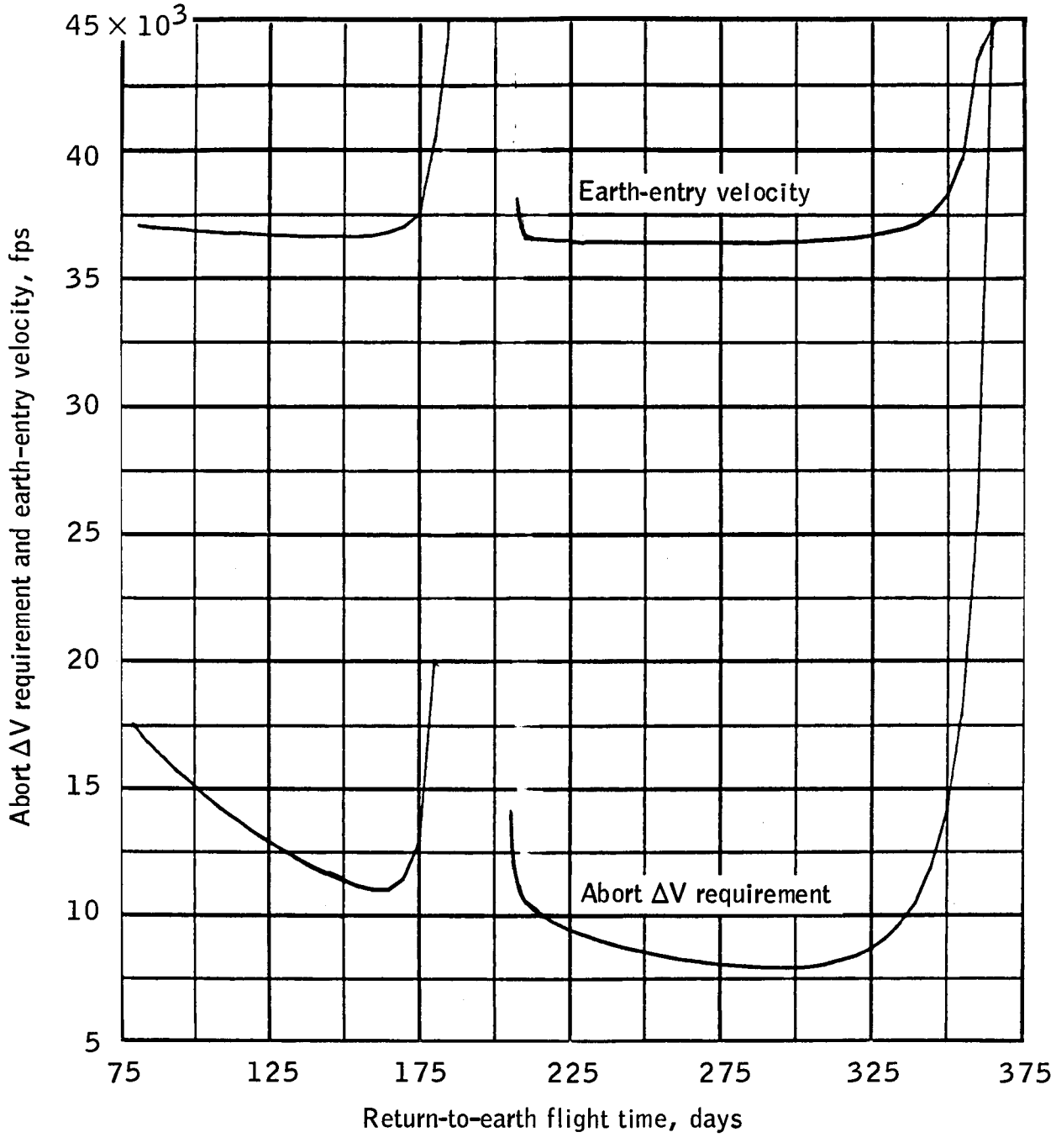

(e) Elapsed time to abort is 25 days after TMI.

Figure 7.- Continued.



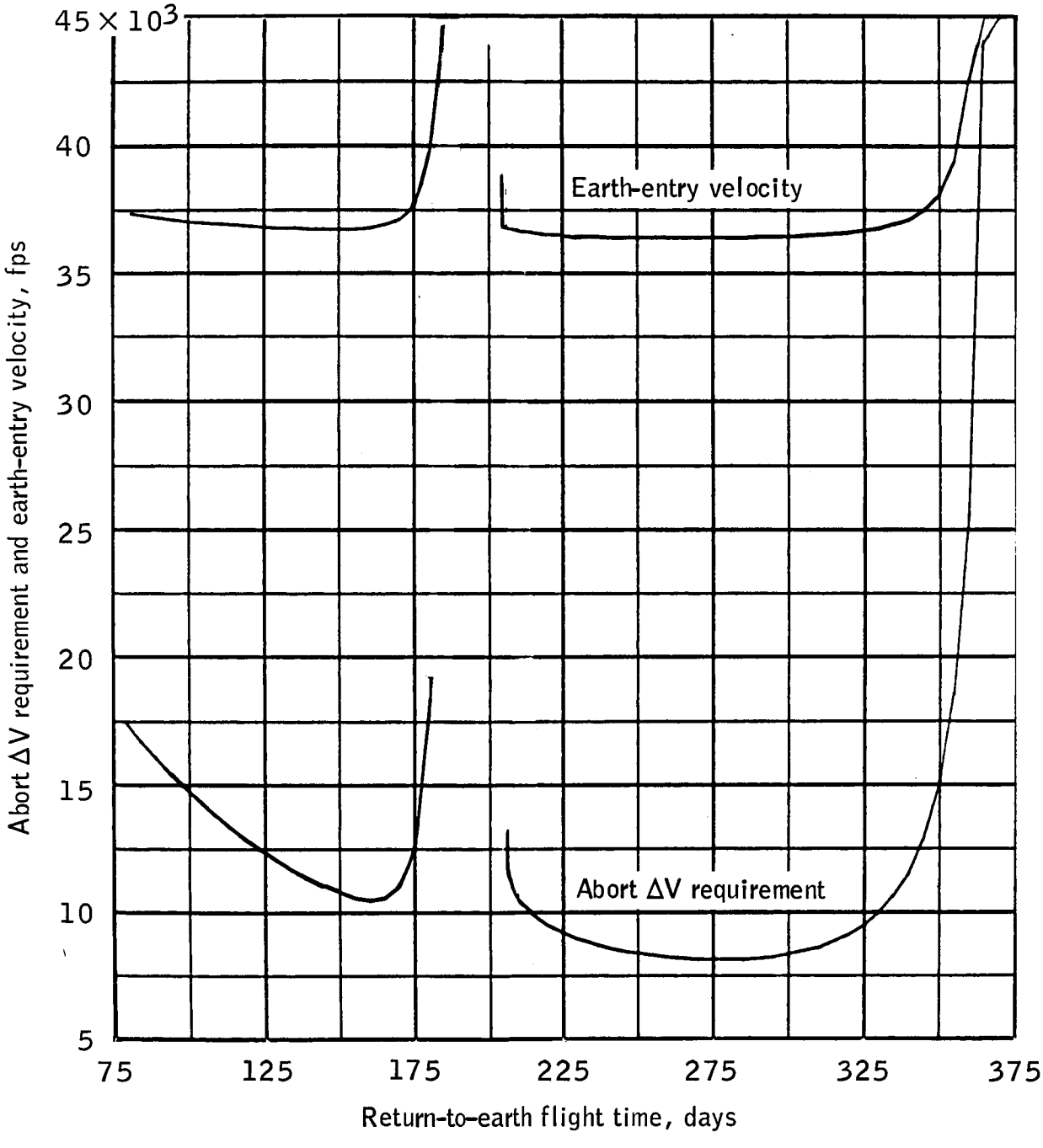

(f) Elapsed time to abort is 30 days after TMI.

Figure 7.- Continued.



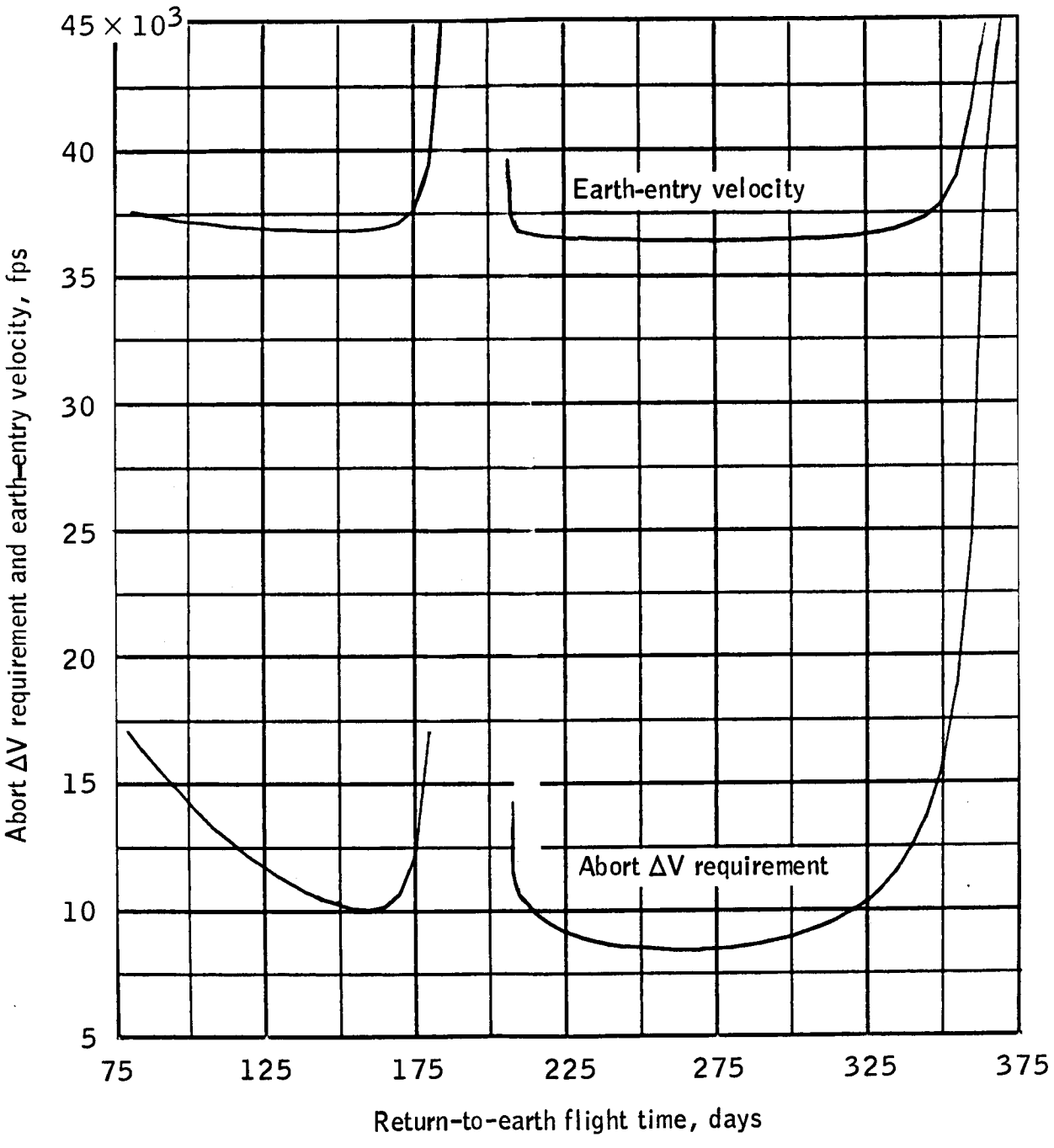

(g) Elapsed time to abort is 35 days after TMI.

Figure 7.- Continued.



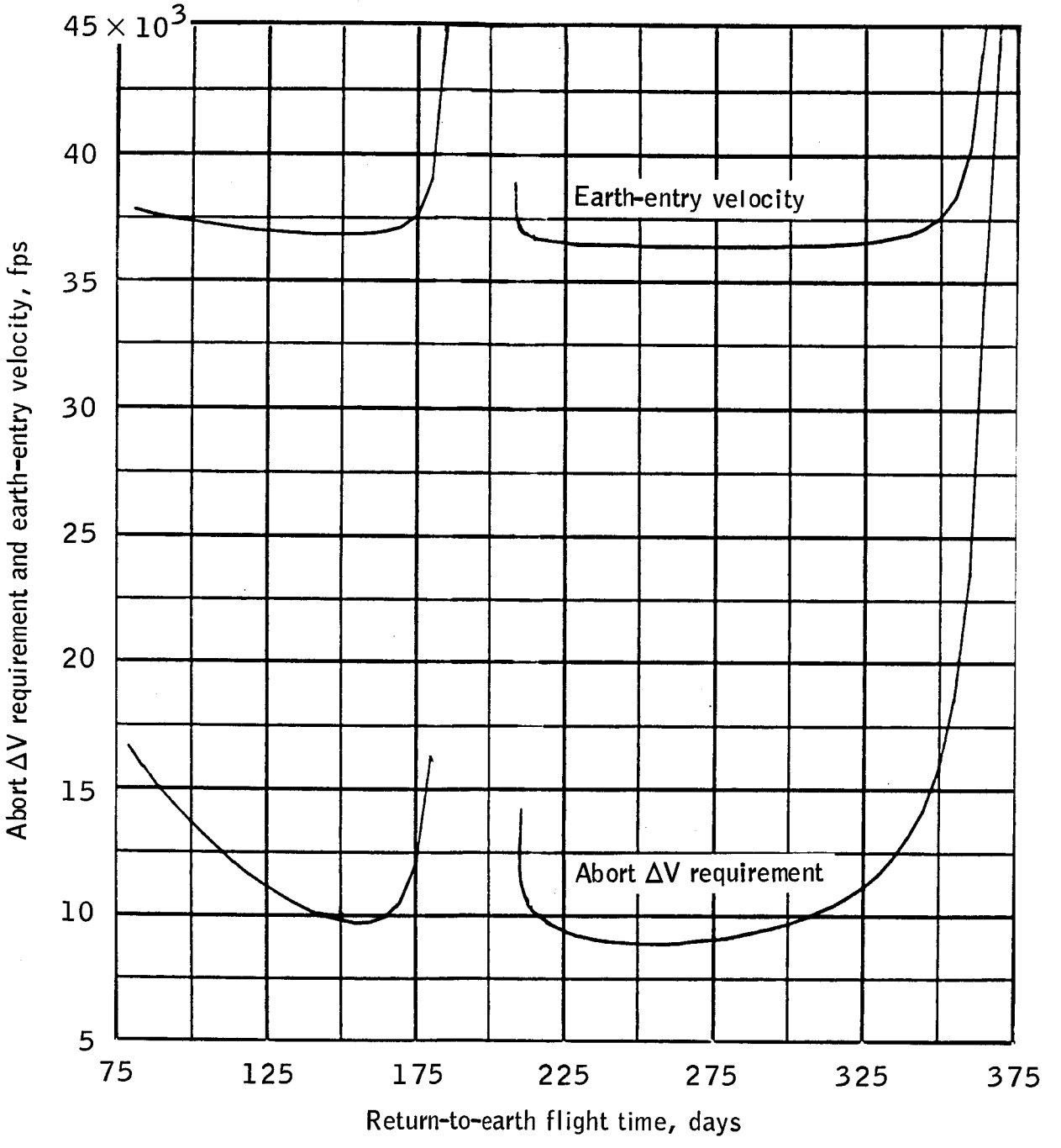

(h) Elapsed time to abort is 40 days after TMI.

Figure 7.- Continued.



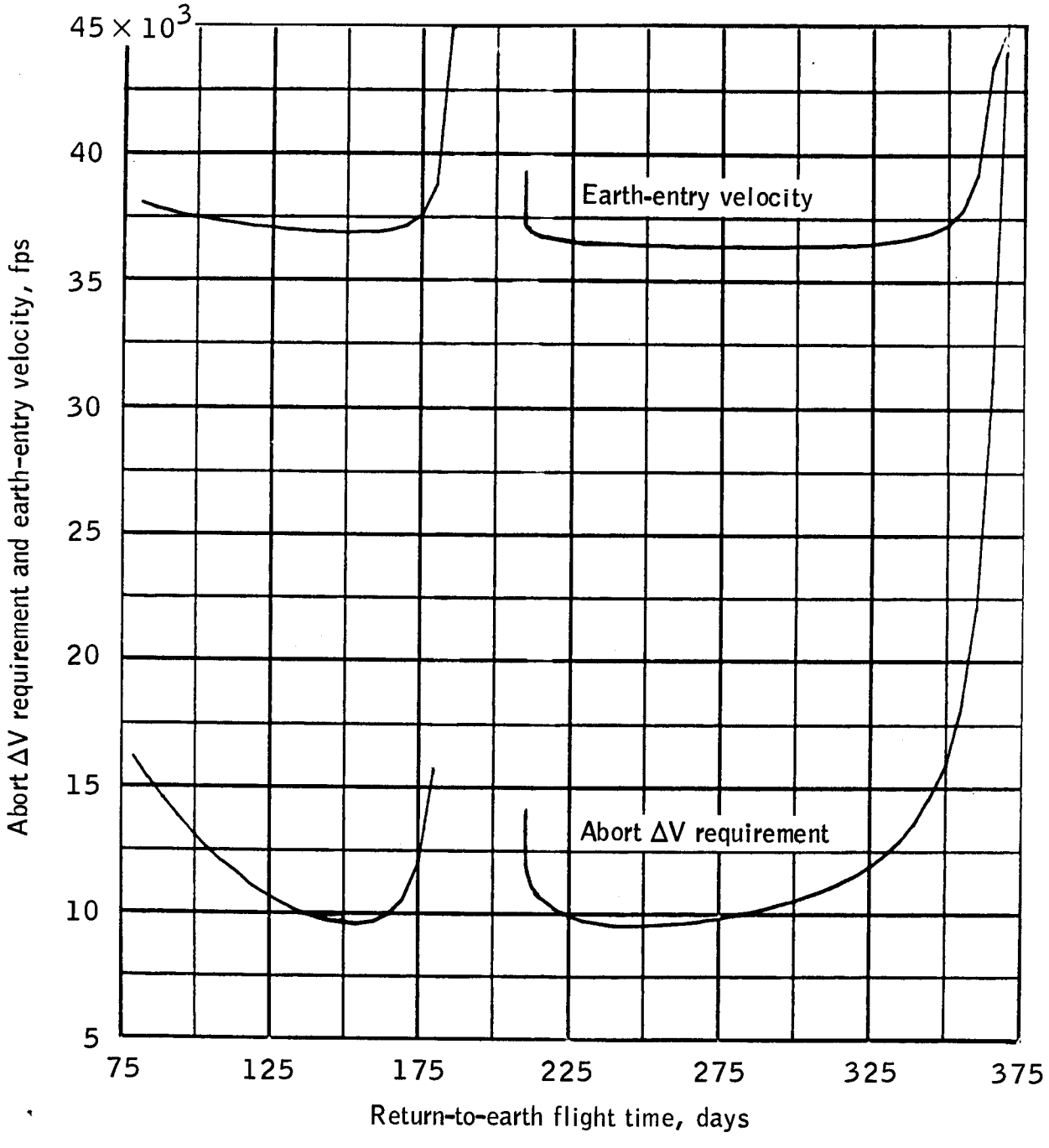

(i) Elapsed time to abort is 45 days after TMI.

Figure 7.- Continued.



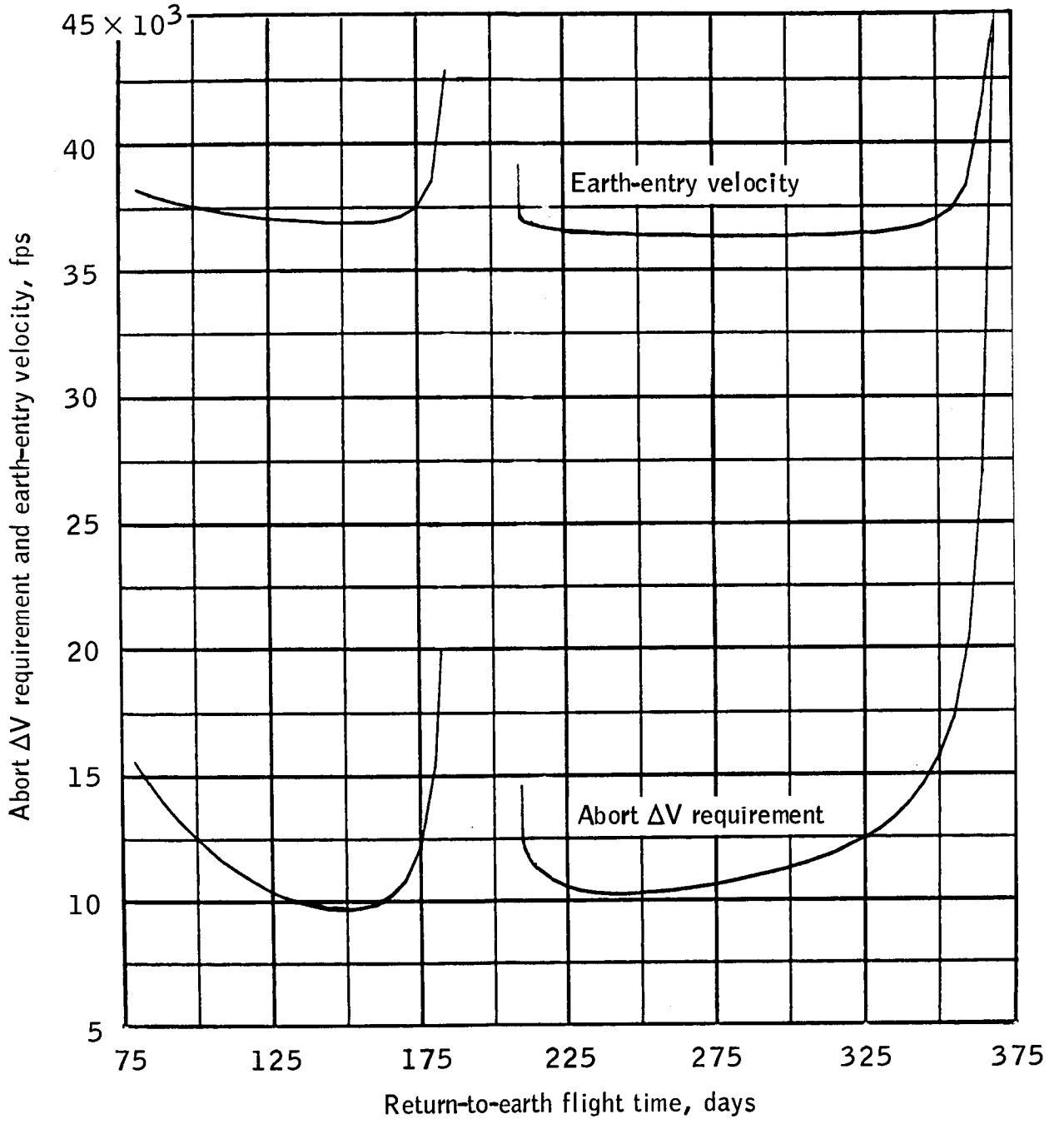

(j) Elapsed time to abort is 50 days after TMI.

Figure 7.- Continued.



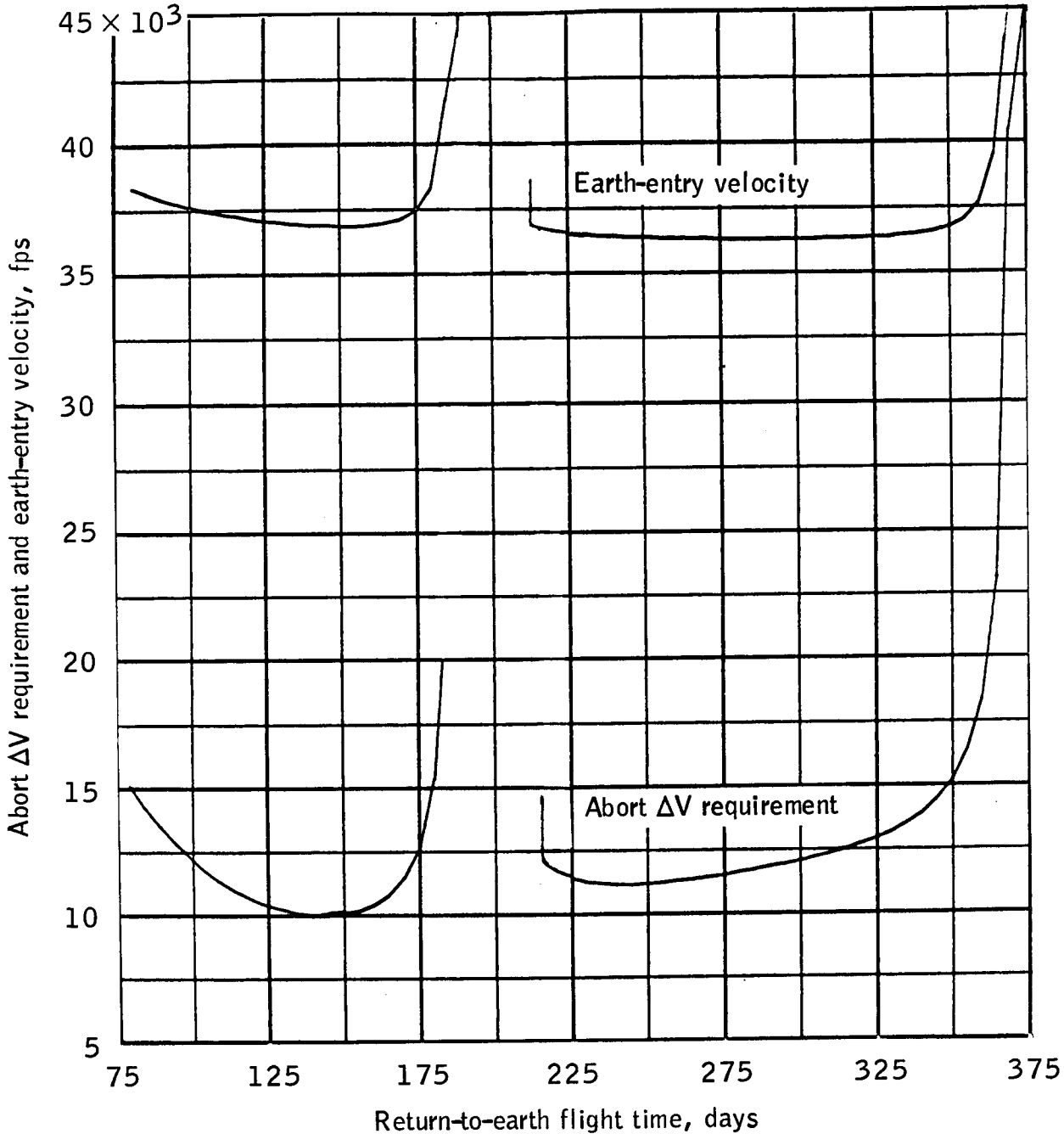

(k) Elapsed time to abort is 55 days after TMI.

Figure 7.- Continued.



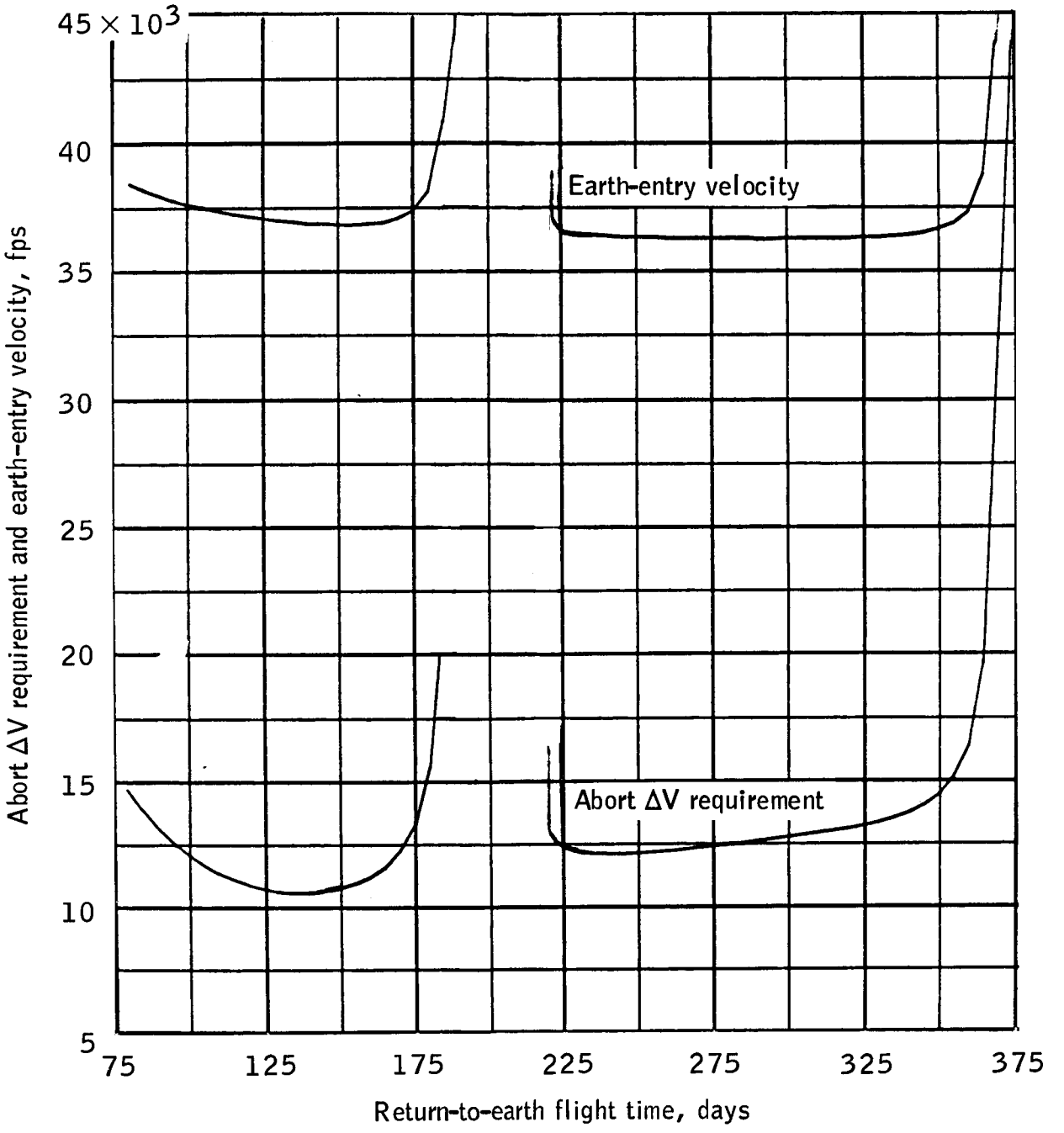

(l) Elapsed time to abort is 60 days after TMI.

Figure 7.- Continued.



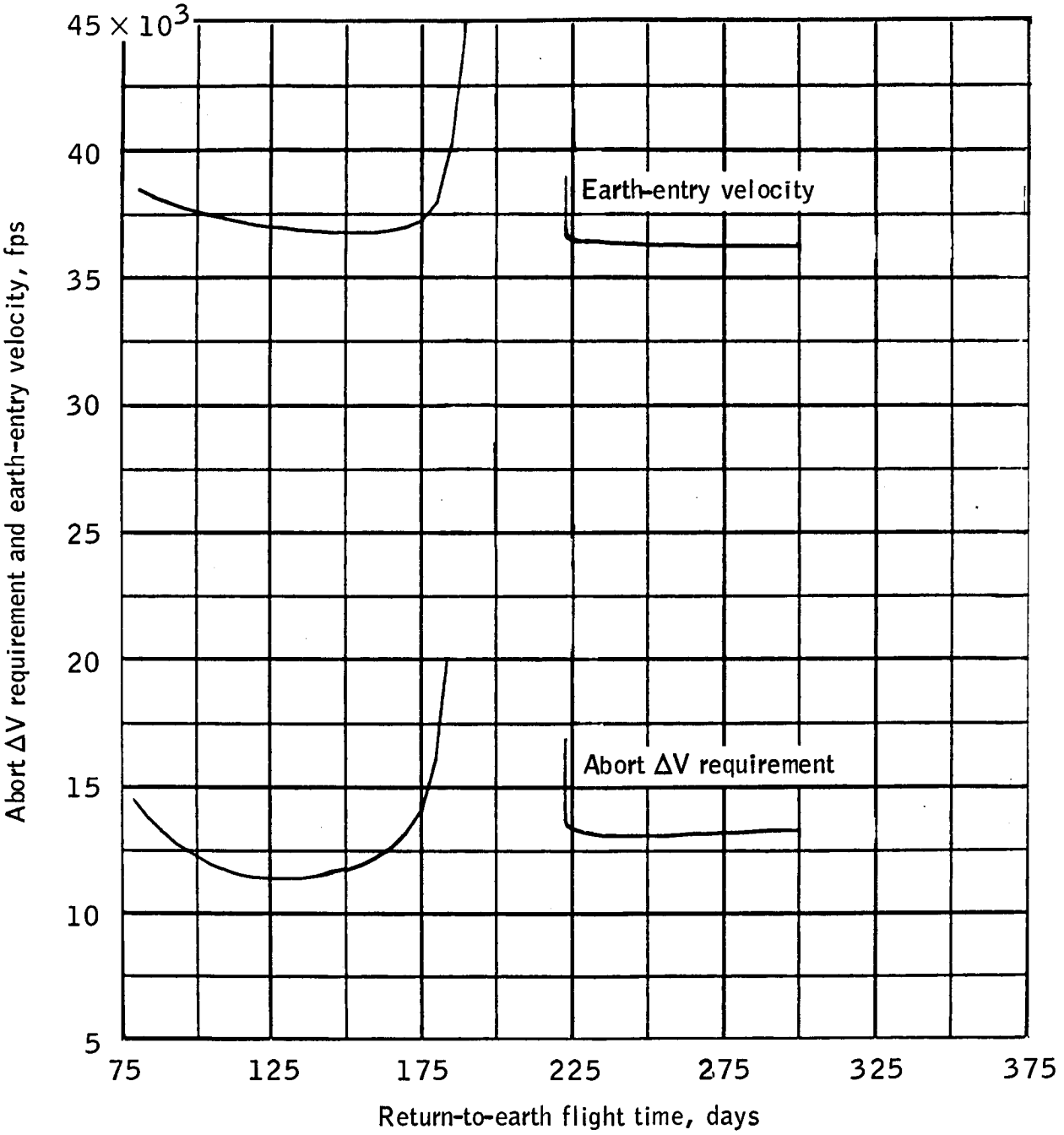

(m) Elapsed time to abort is 65 days after TMI.

Figure 7.- Continued.



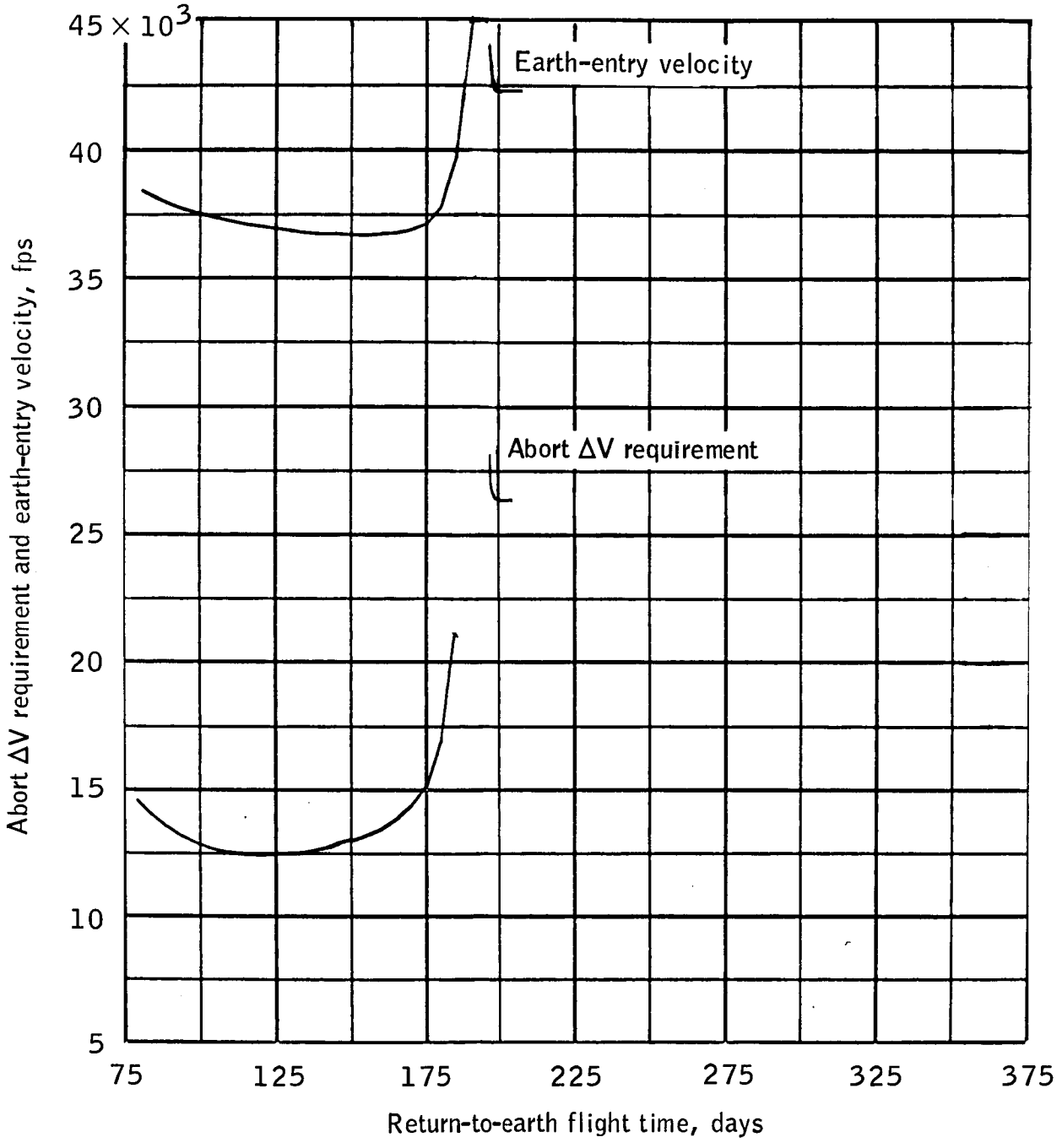

(n) Elapsed time to abort is 70 days after TMI.

Figure 7.- Continued.



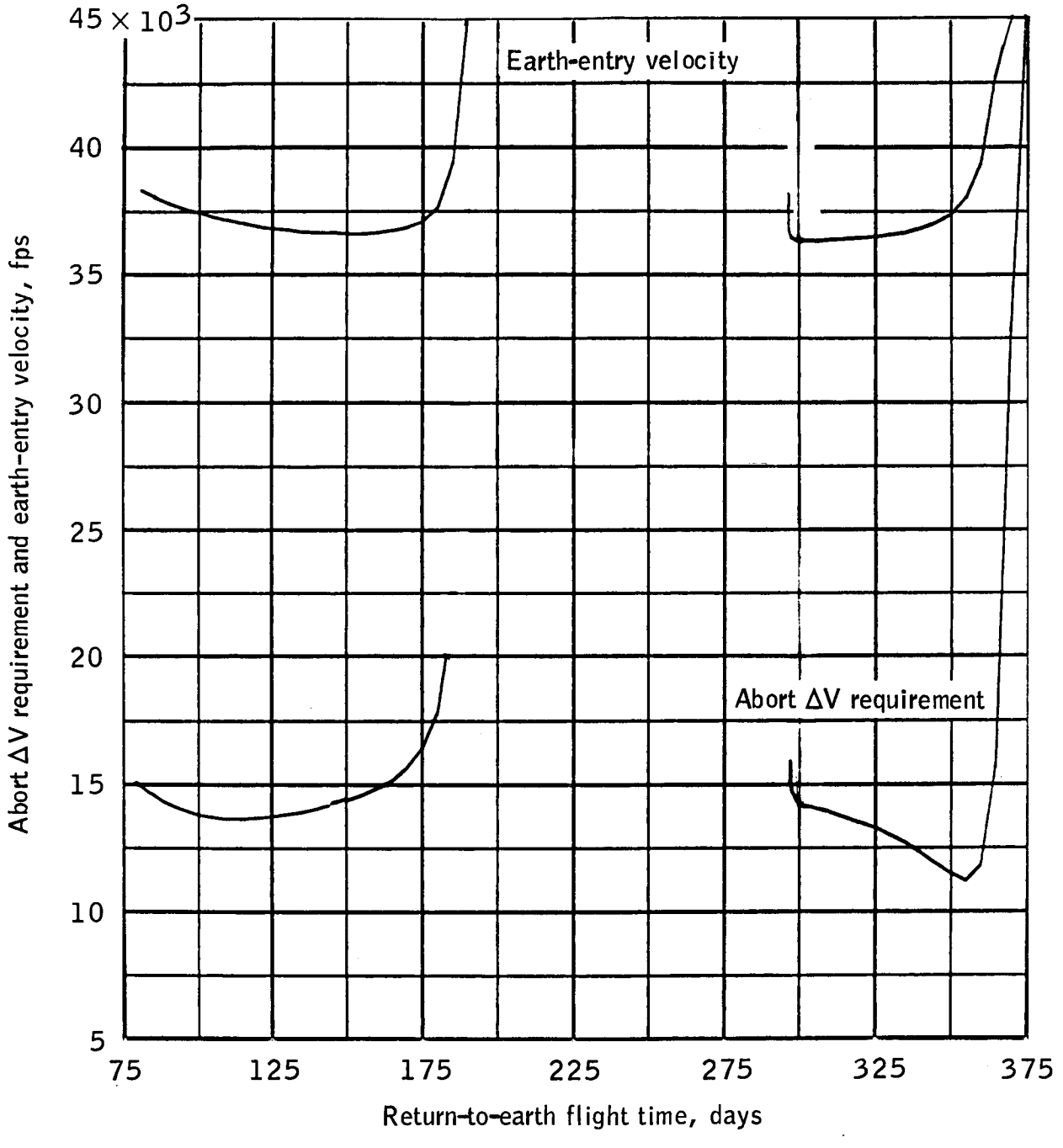

(o) Elapsed time to abort is 75 days after TMI.

Figure 7.- Continued.



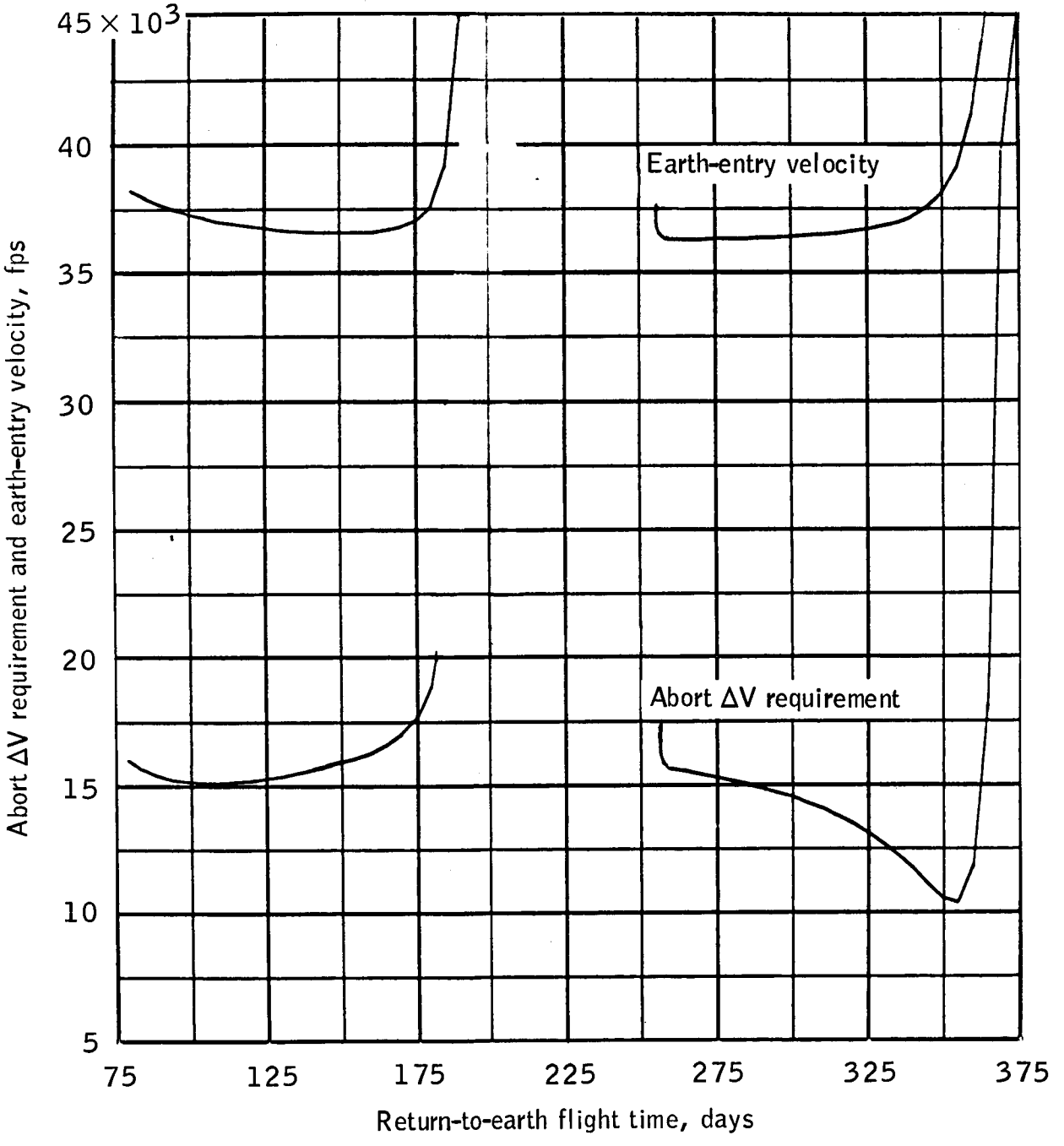

(p) Elapsed time to abort is 80 days after TMI.

Figure 7.- Continued.



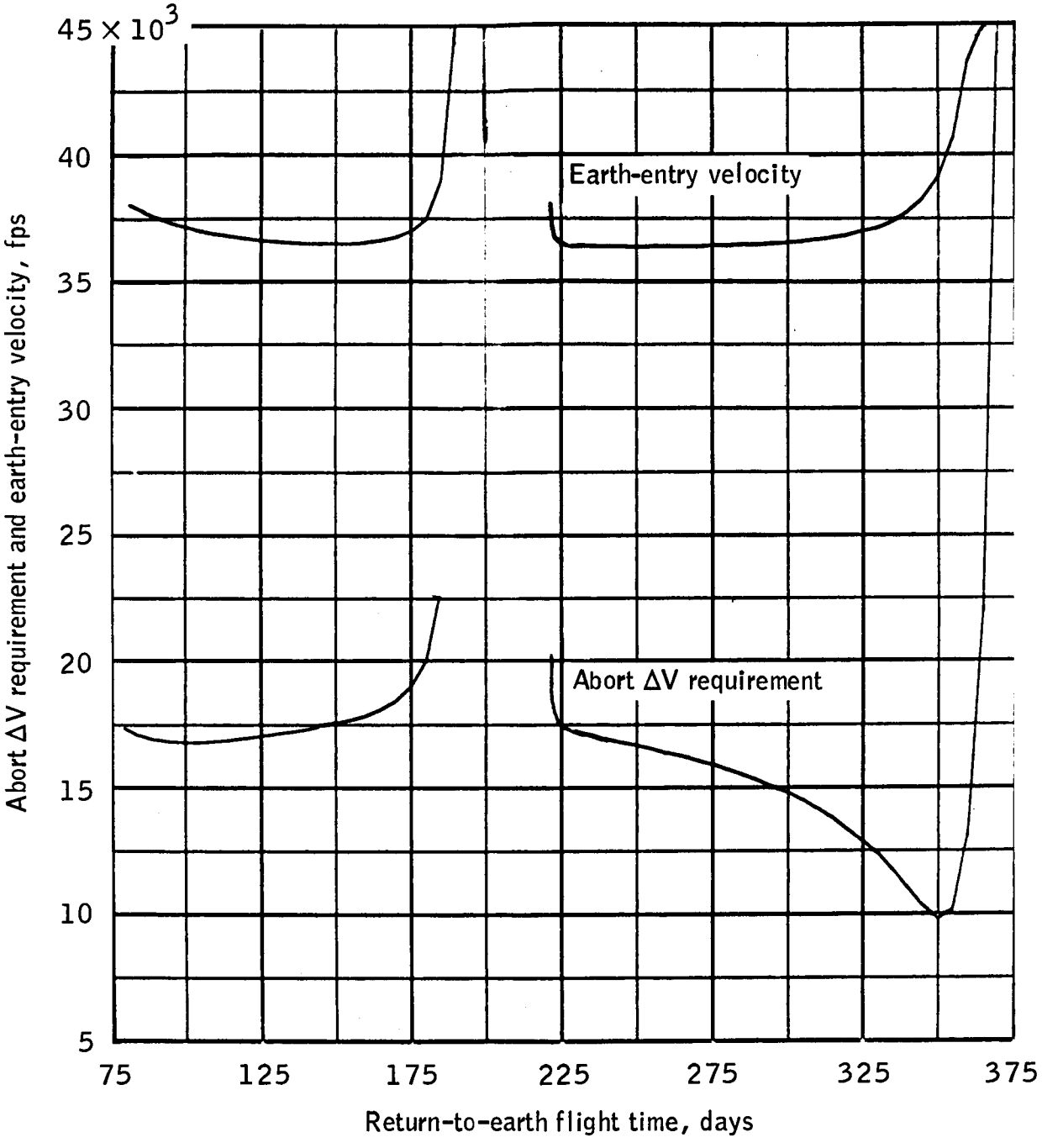

(q) Elapsed time to abort is 85 days after TMI.

Figure 7.- Continued.



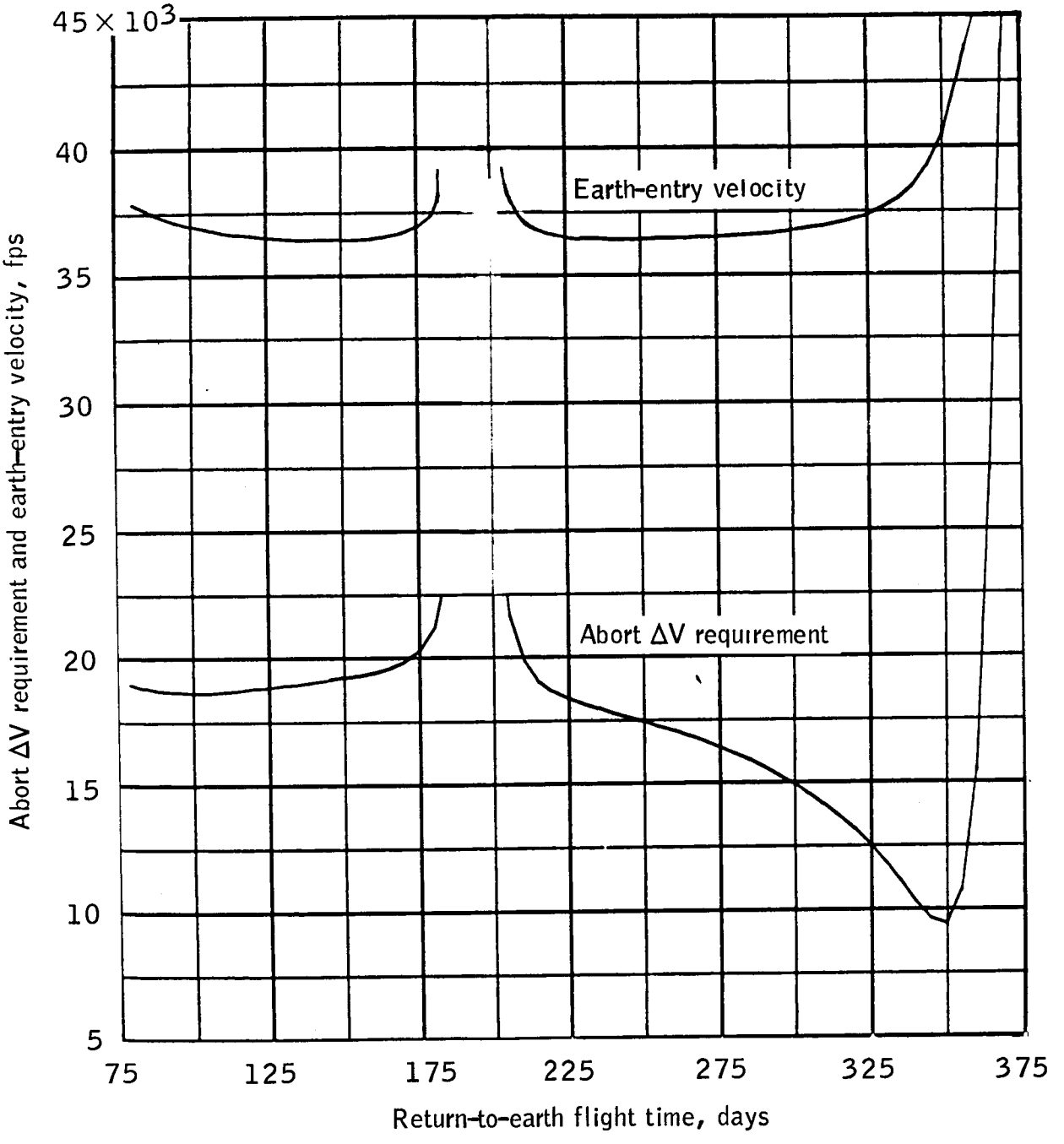

(r) Elapsed time to abort is 90 days after TMI.

Figure 7.- Continued.



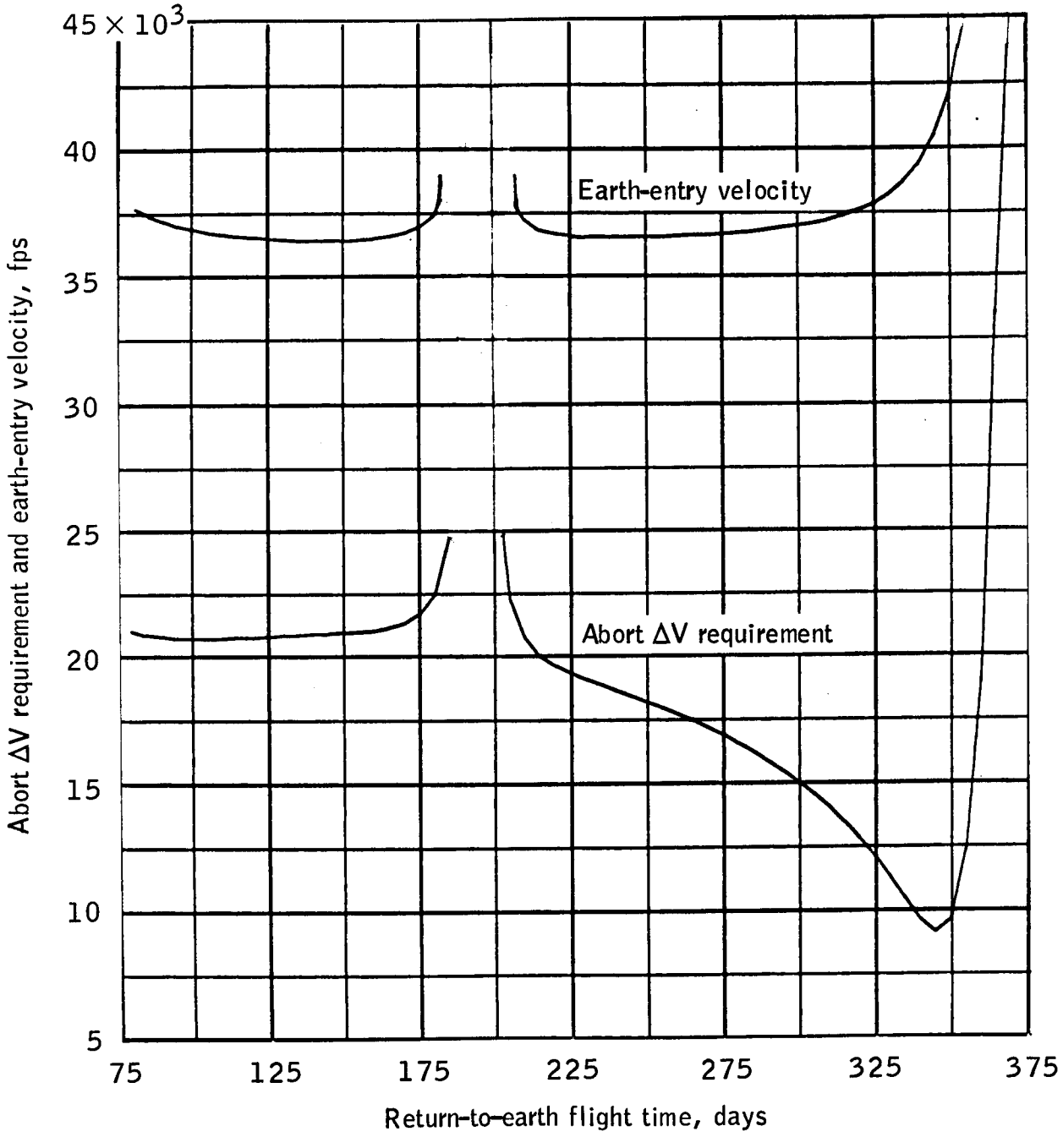

(s) Elapsed time to abort is 95 days after TMI.

Figure 7.- Continued.



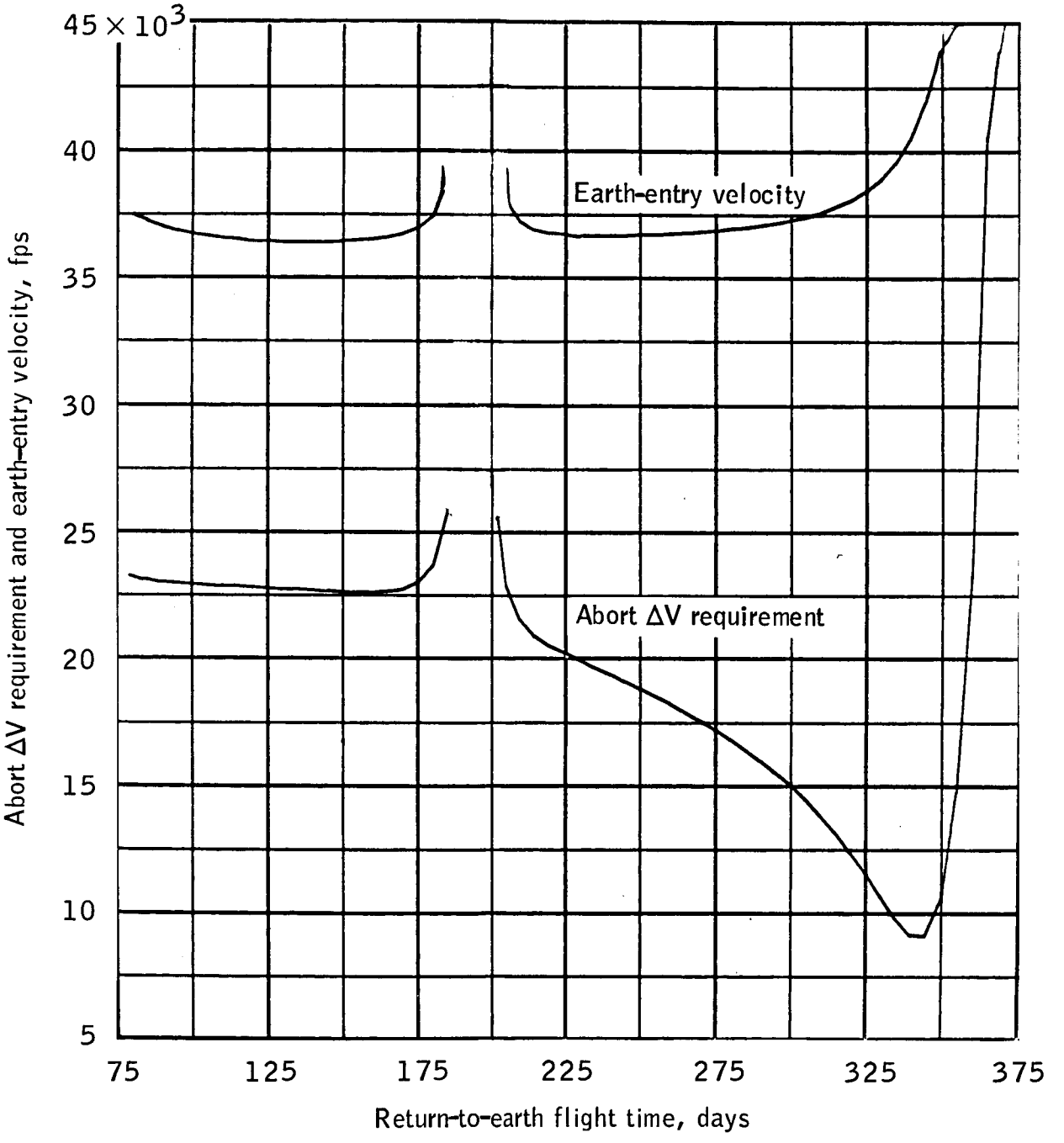

(t) Elapsed time to abort is 100 days after TMI.

Figure 7.- Continued.



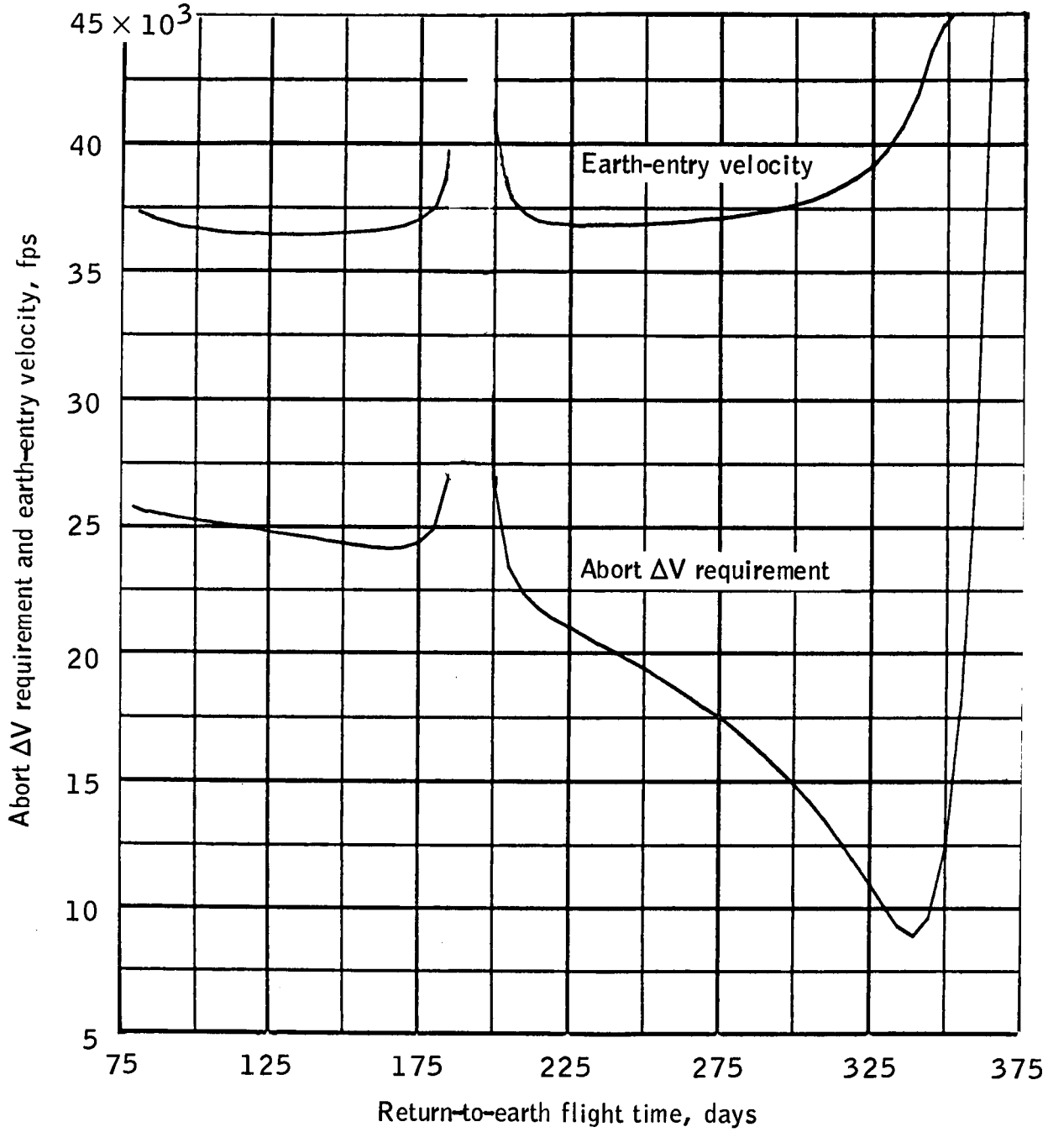

(u) Elapsed time to abort is 105 days after TMI.

Figure 7.- Continued.



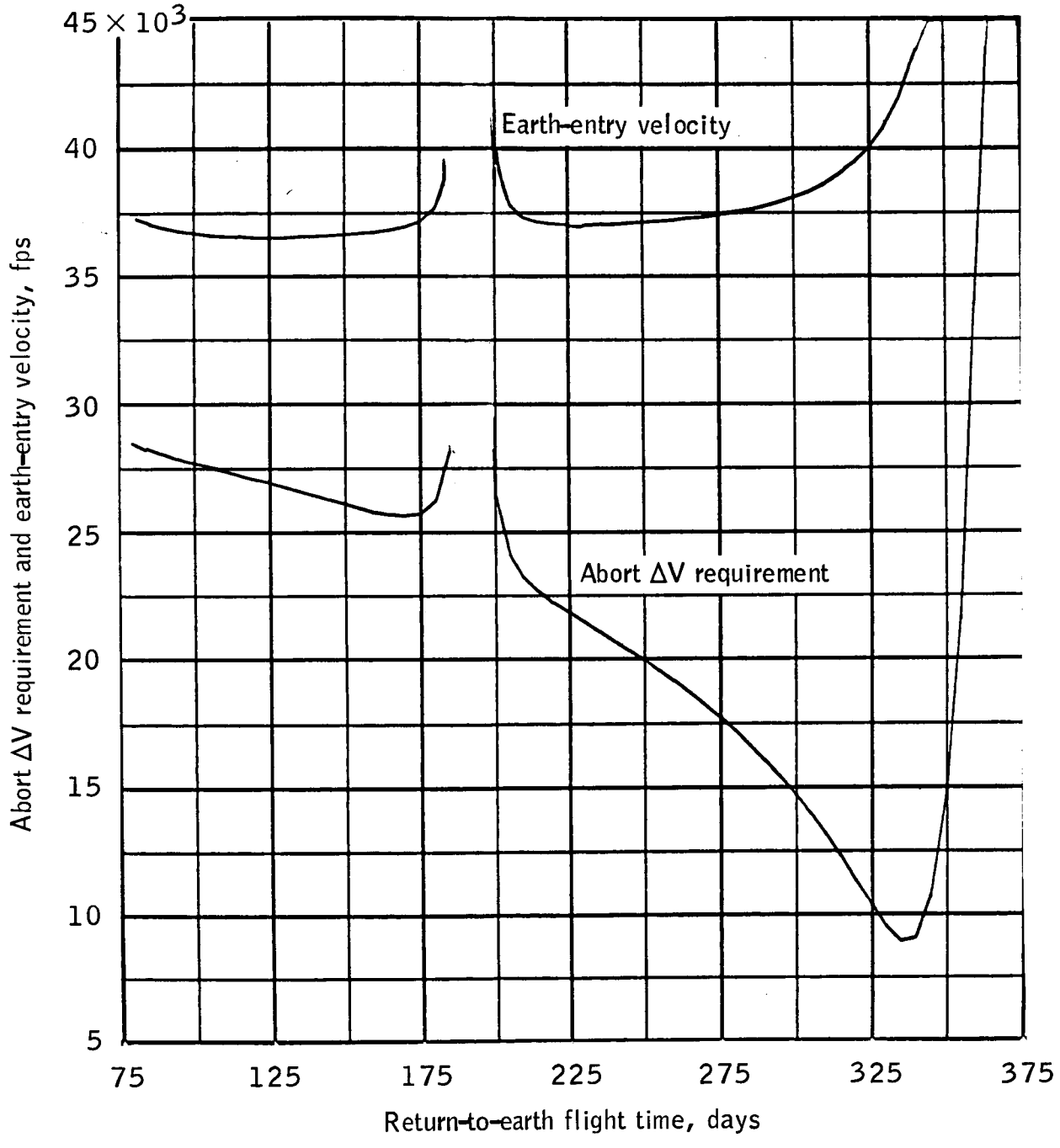

(v) Elapsed time to abort is 110 days after TMI.

Figure 7.- Continued.



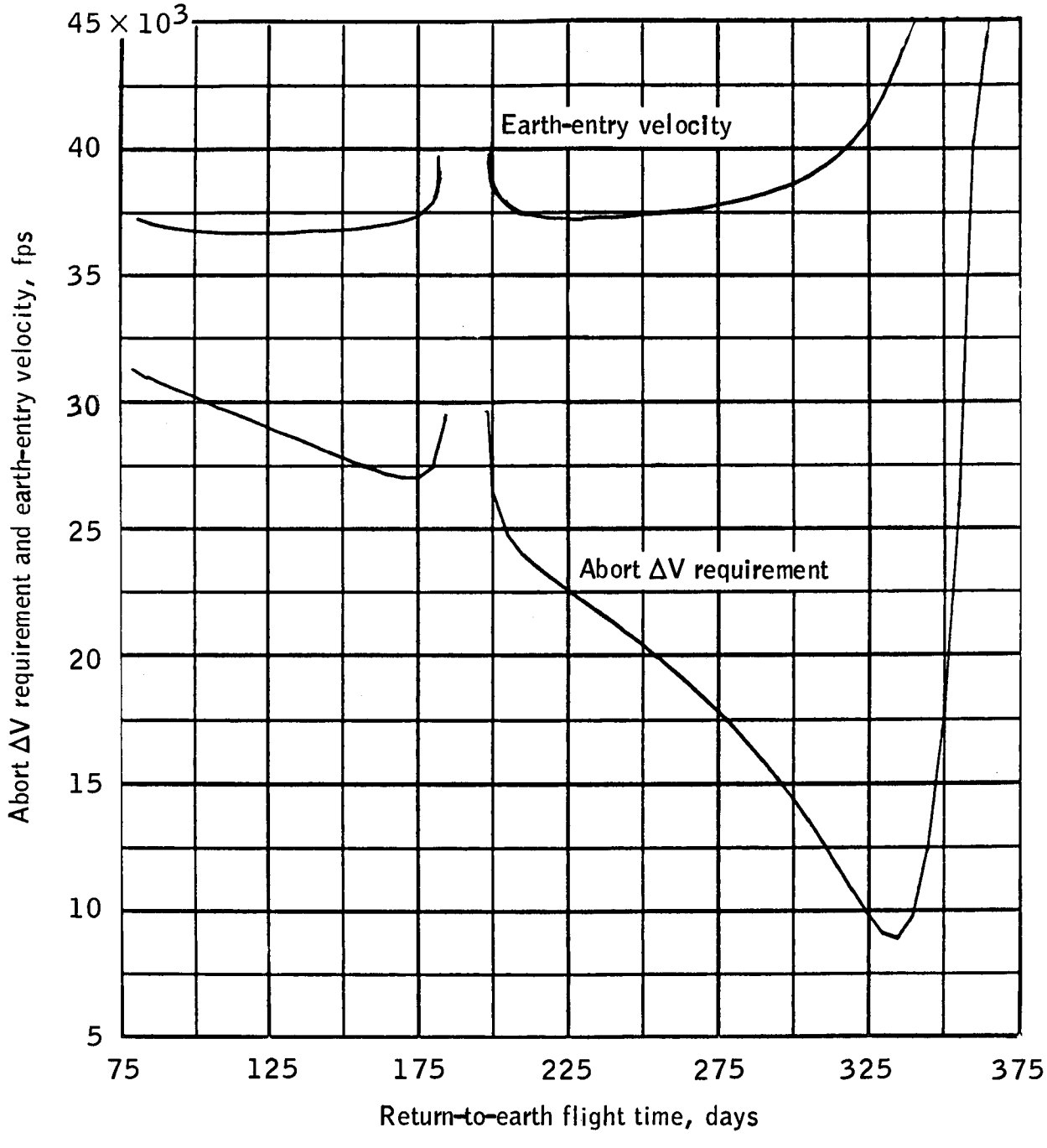

(w) Elapsed time to abort is 115 days after TMI.

Figure 7.- Continued.



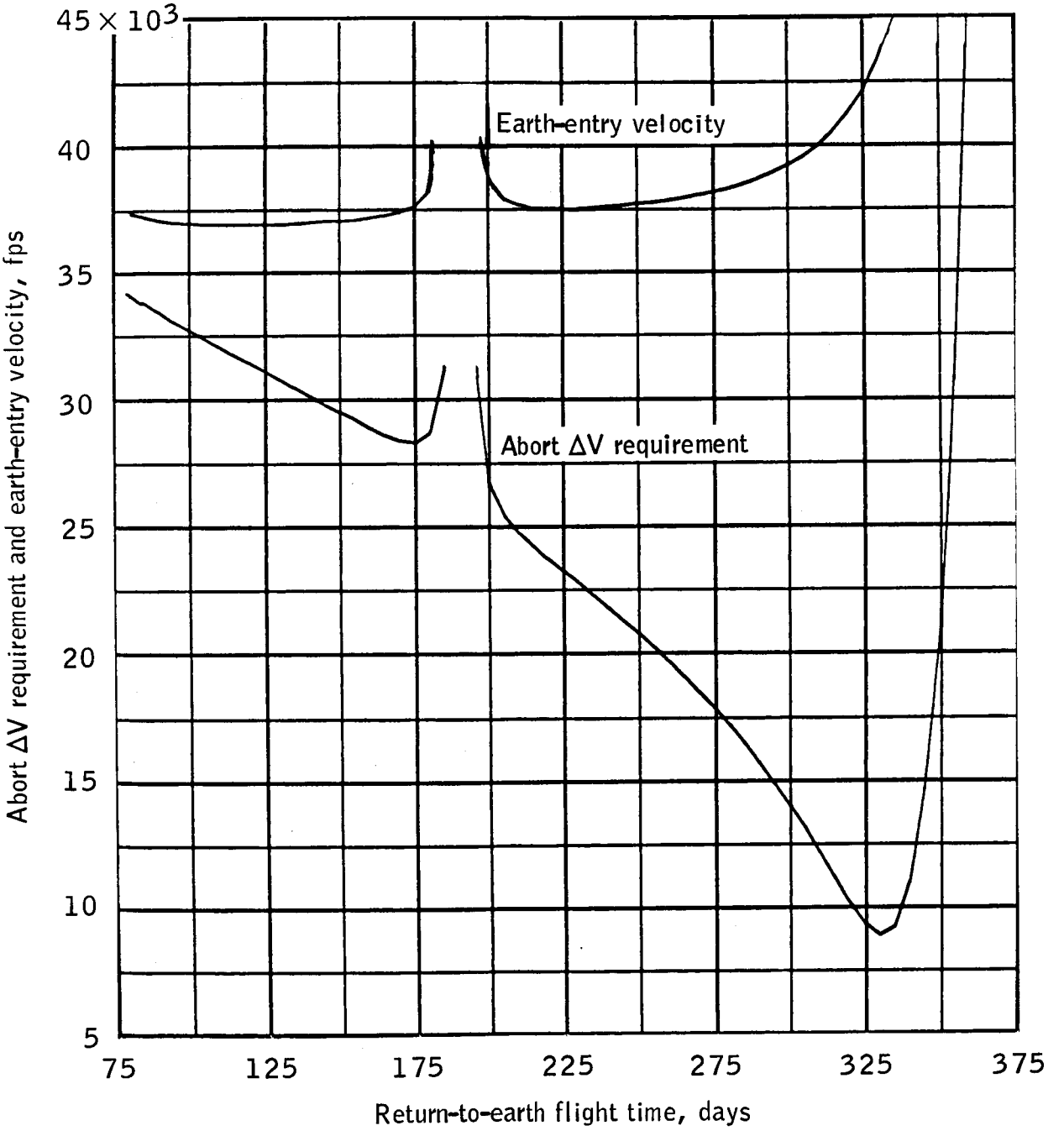

(x) Elapsed time to abort is 120 days after TMI.

Figure 7.- Continued.



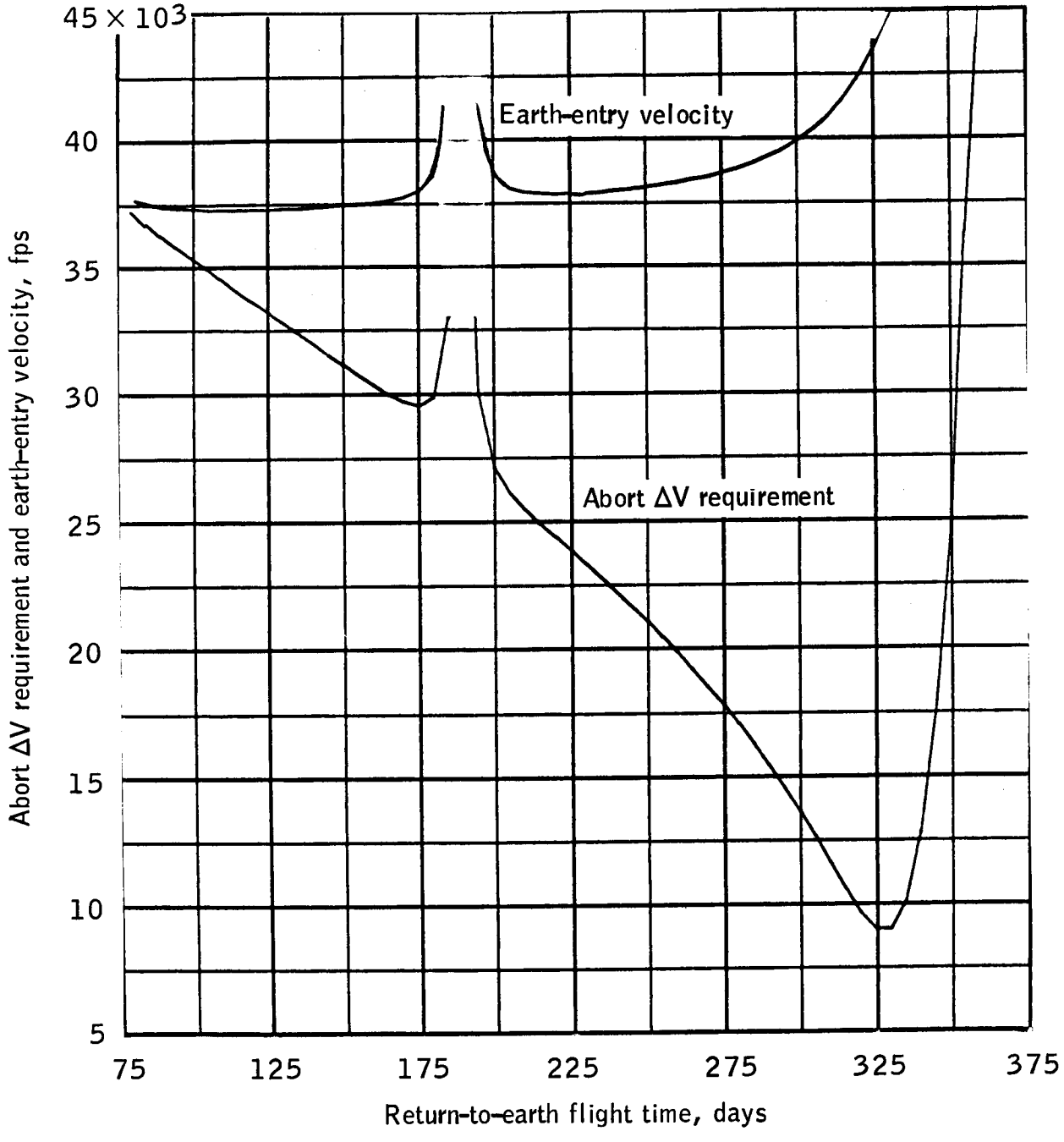

(y) Elapsed time to abort is 125 days after TMI.

Figure 7.- Continued.



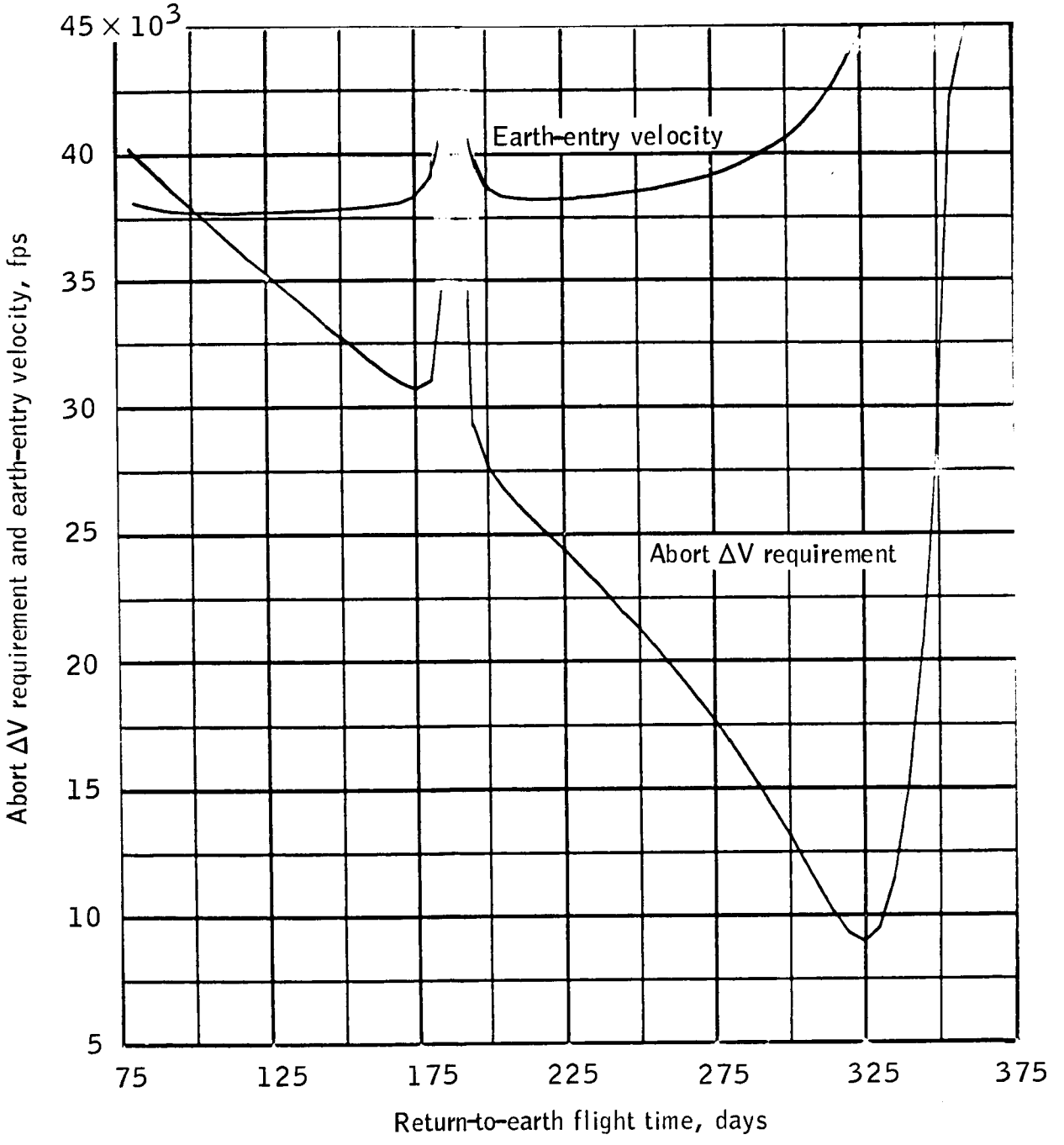

(z) Elapsed time to abort is 130 days after TMI.

Figure 7.- Continued.



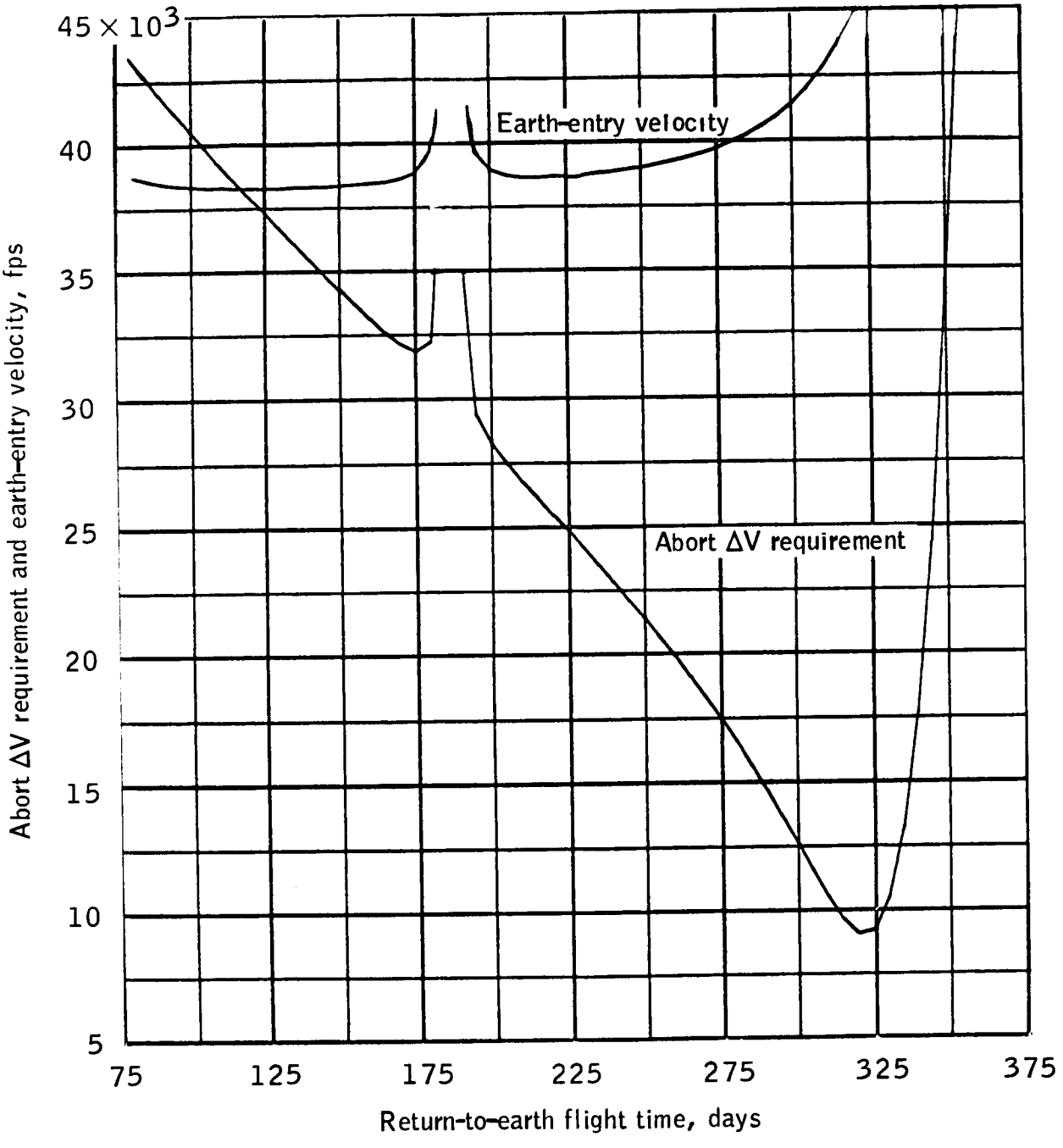

(aa) Elapsed time to abort is 135 days after TMI.

Figure 7.- Continued.



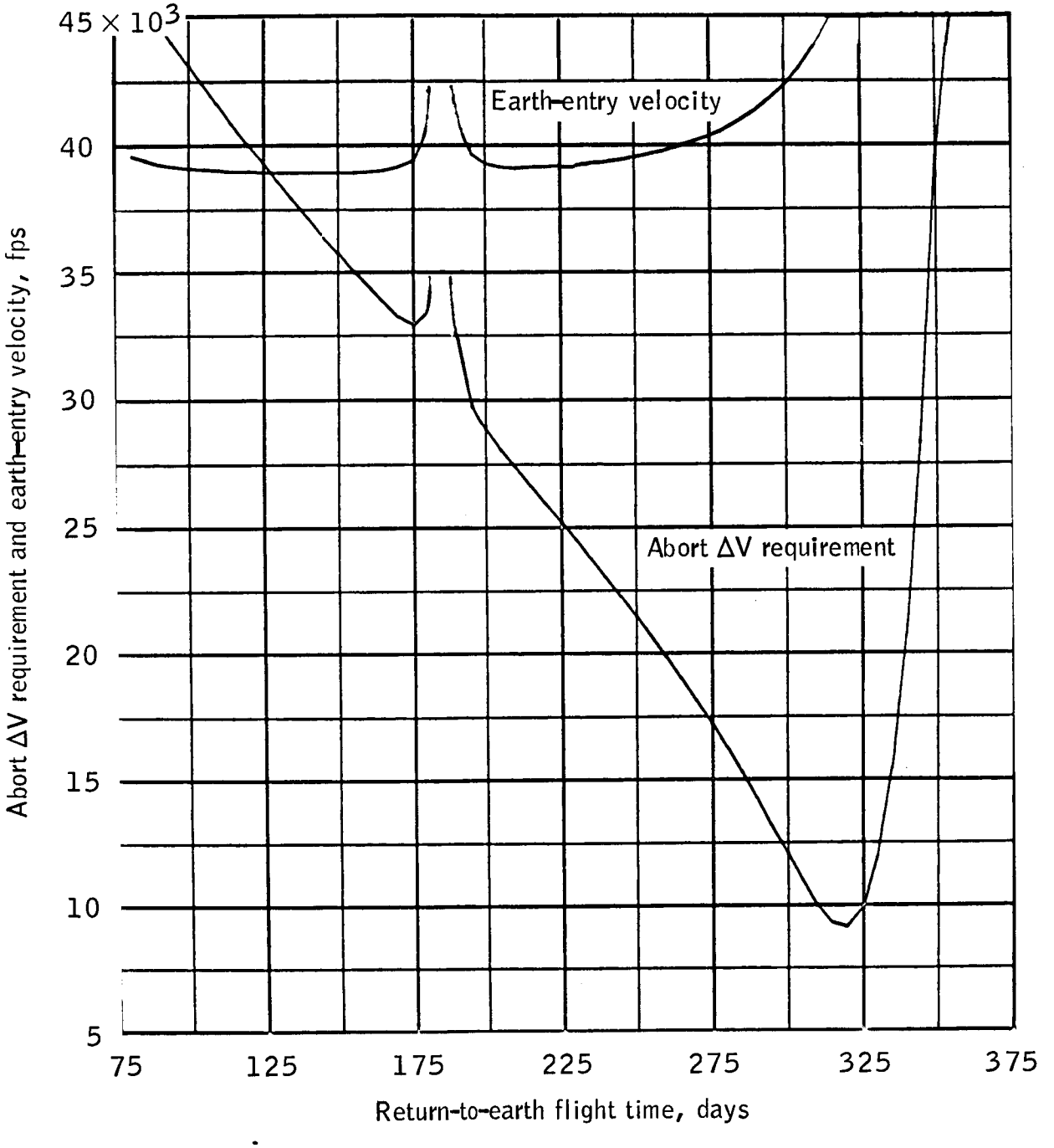

(bb) Elapsed time to abort is 140 days after TMI.

Figure 7.- Continued.



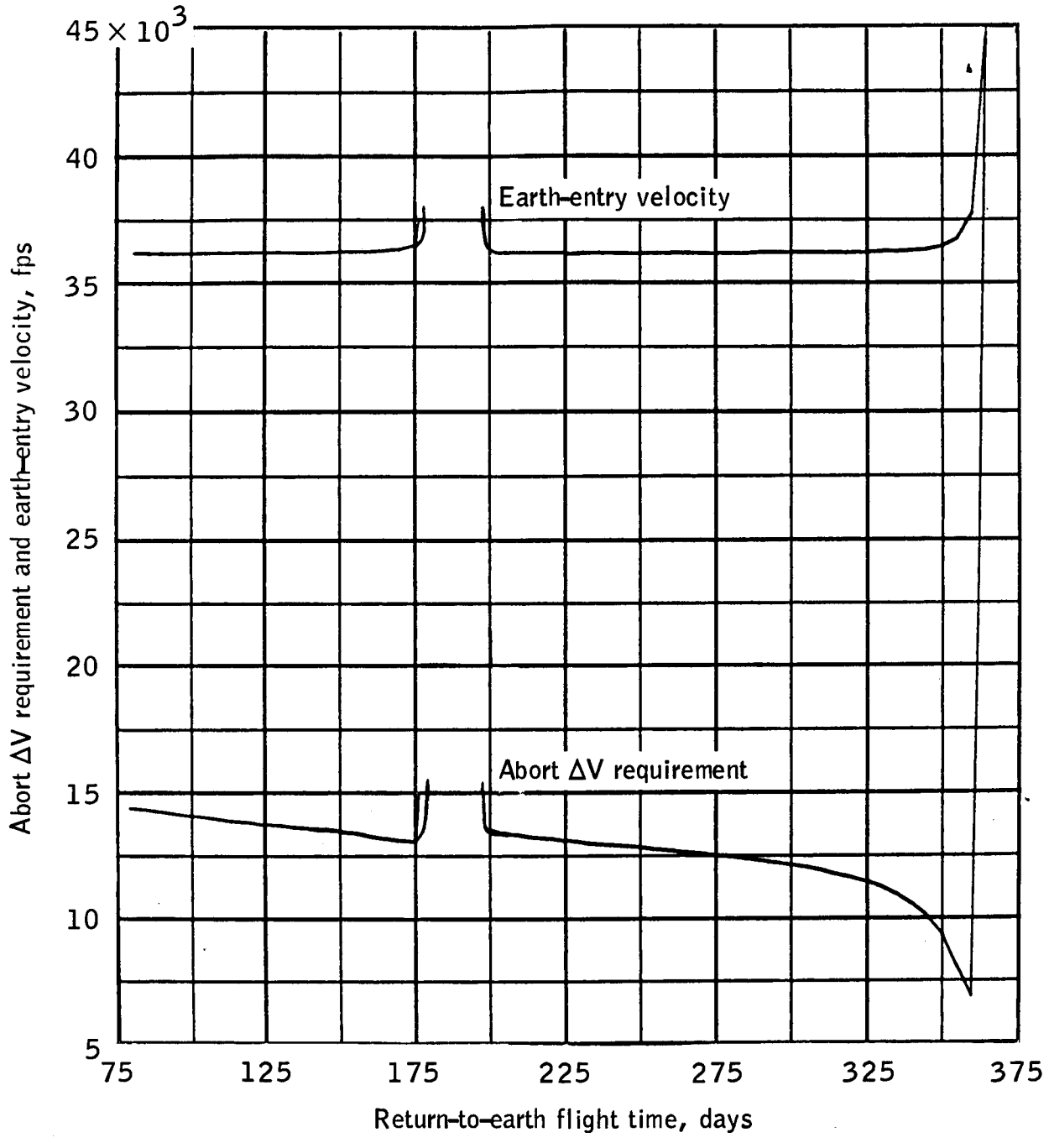

(cc) Elapsed time to abort is 145 days after TMI.

Figure 7.- Continued.



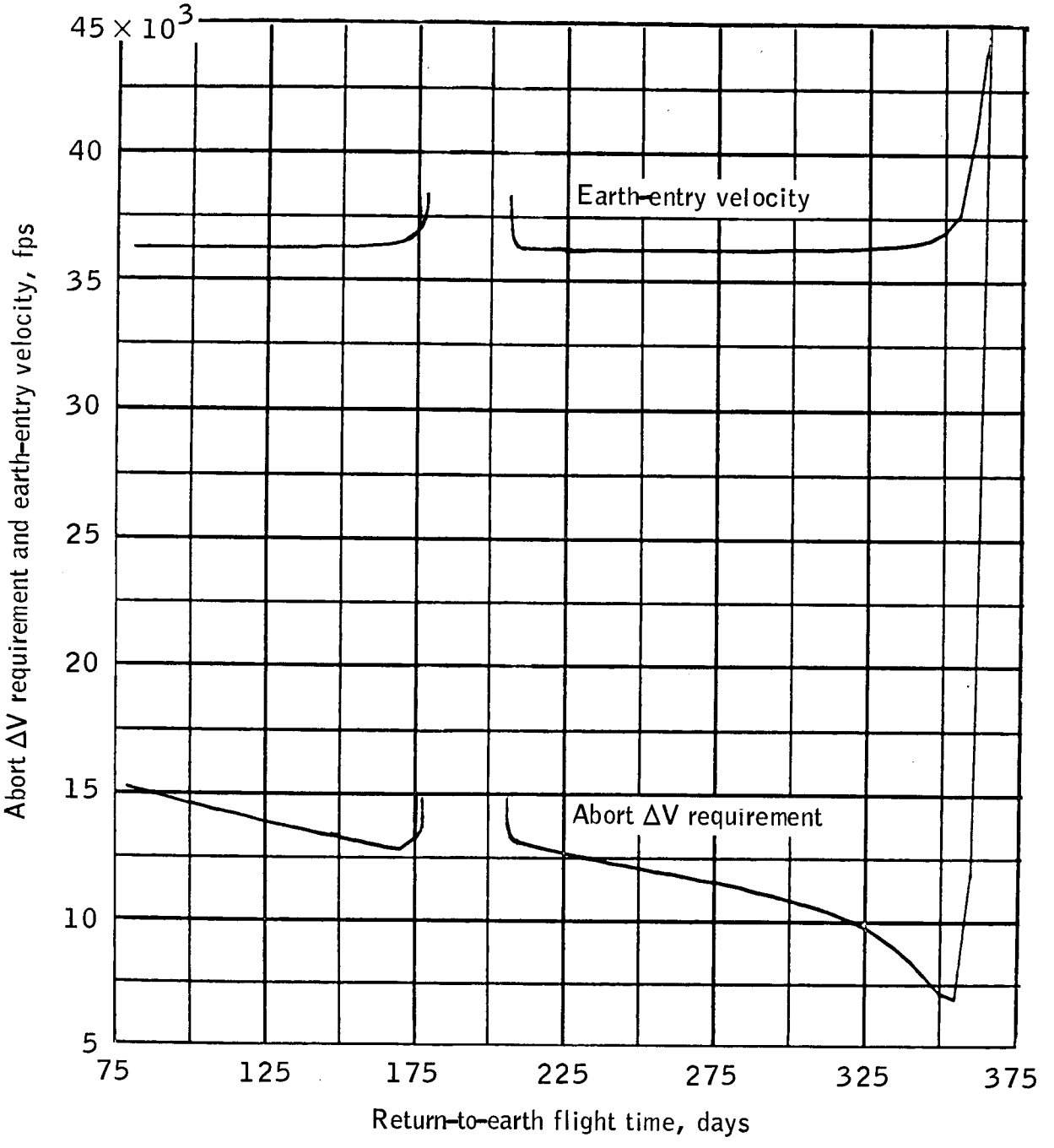

(dd) Elapsed time to abort is 150 days after TMI.

Figure 7.- Concluded.



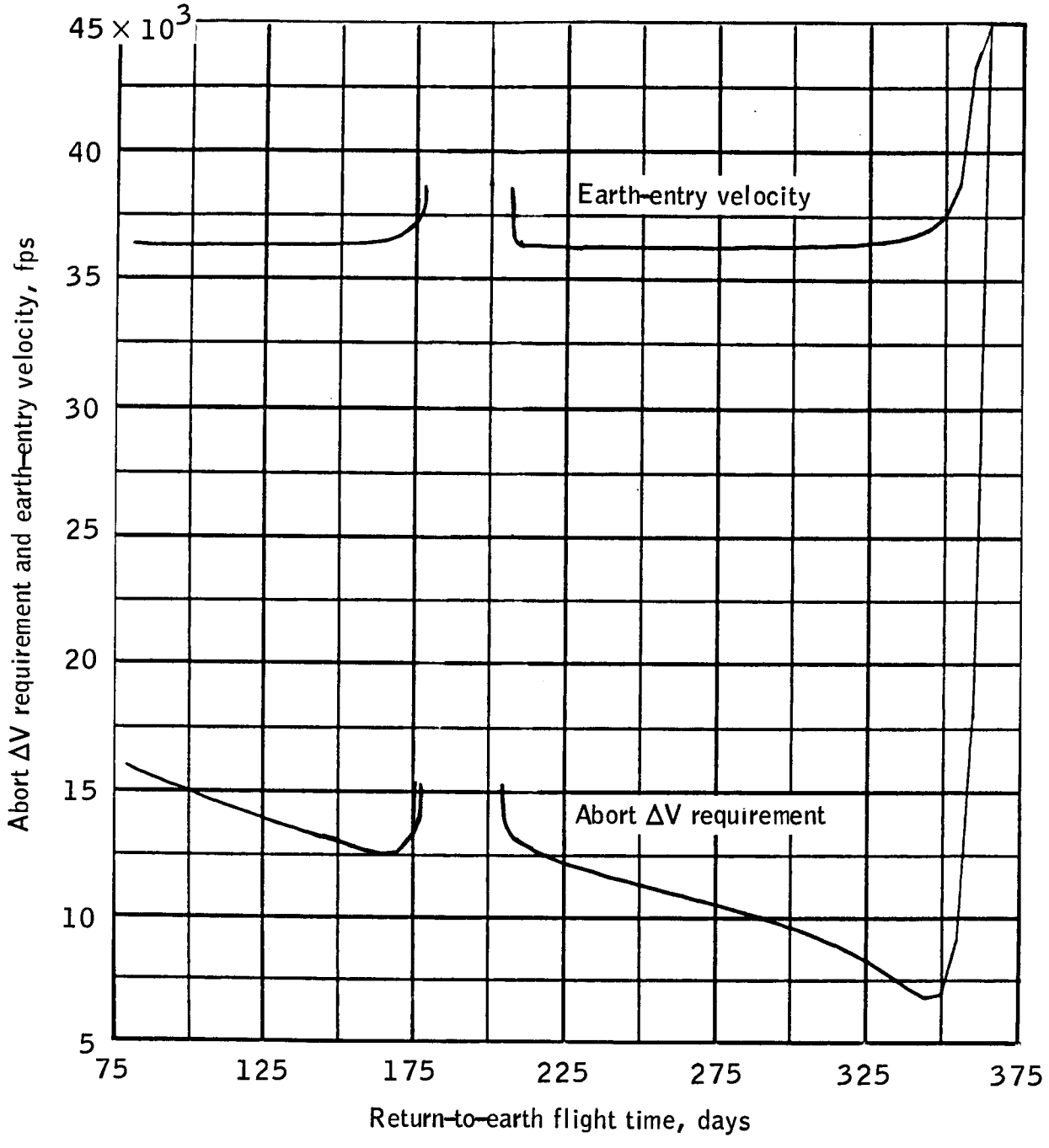

(a) Elapsed time to abort is 5 days after TMI.

Figure 8.- Velocity characteristics of heliocentric abort trajectories, 1983 Mars conjunction class mission.



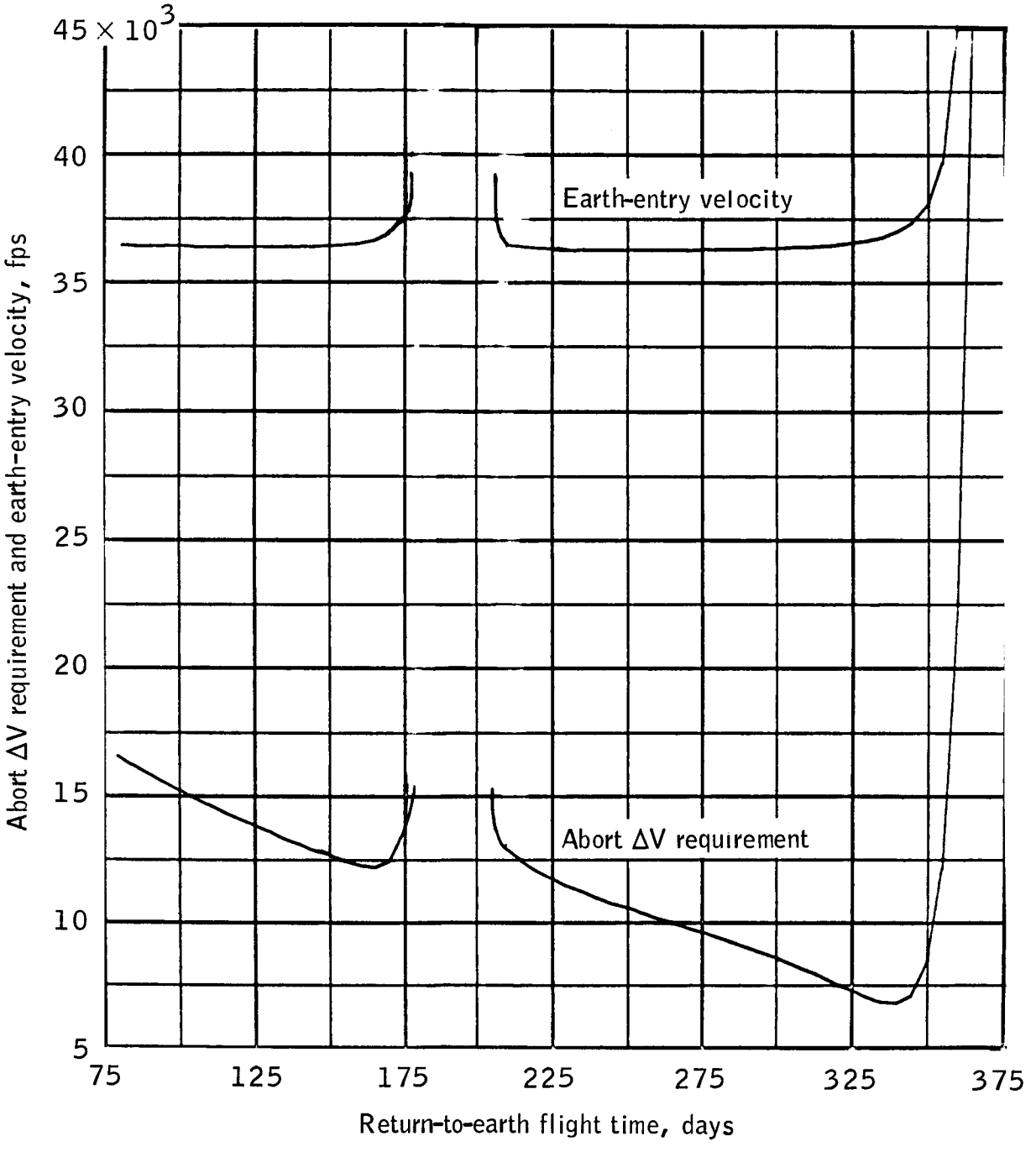

(b) Elapsed time to abort is 10 days after TMI.

Figure 8.- Continued.



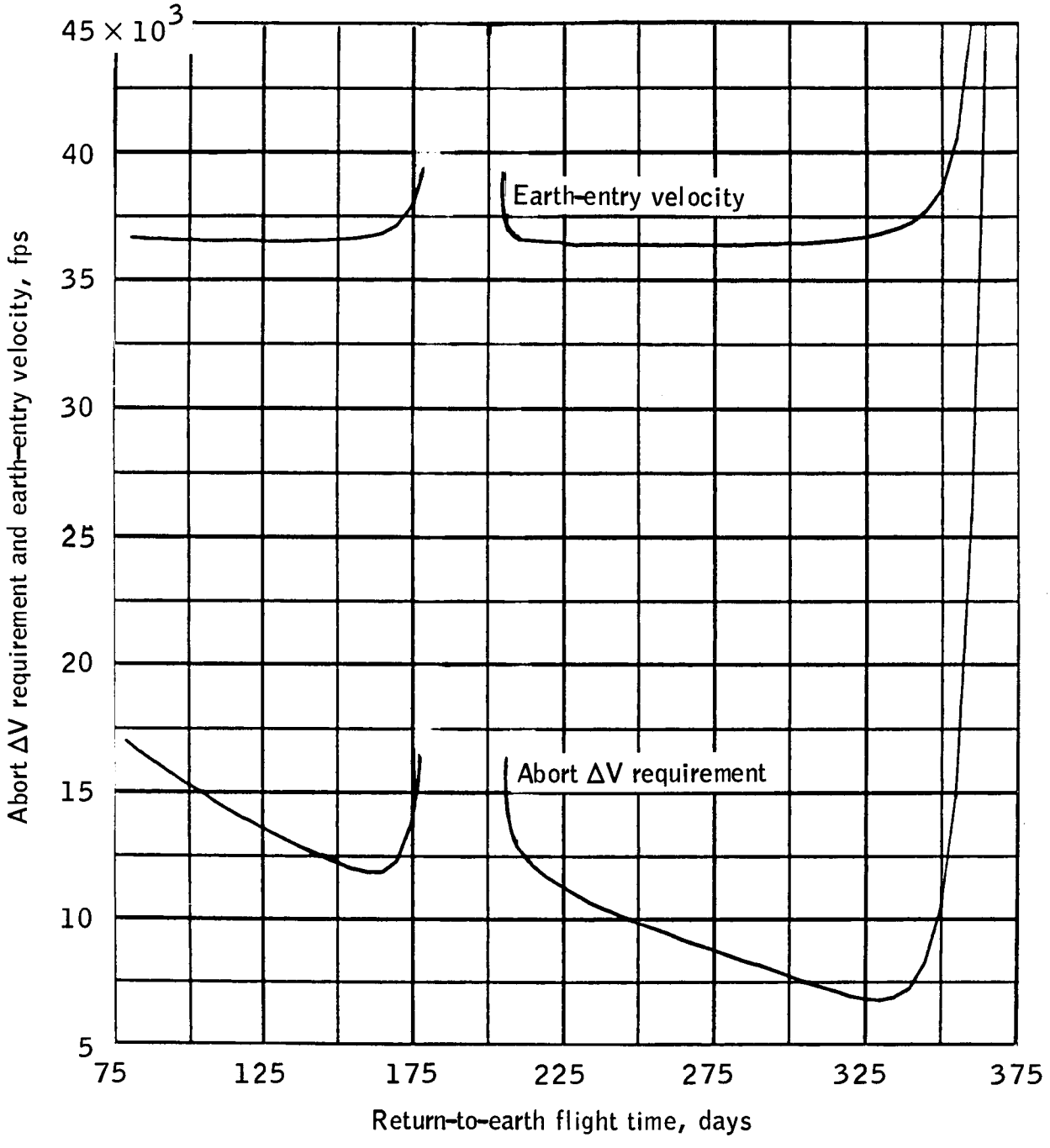

(c) Elapsed time to abort is 15 days after TMI.

Figure 8.- Continued.



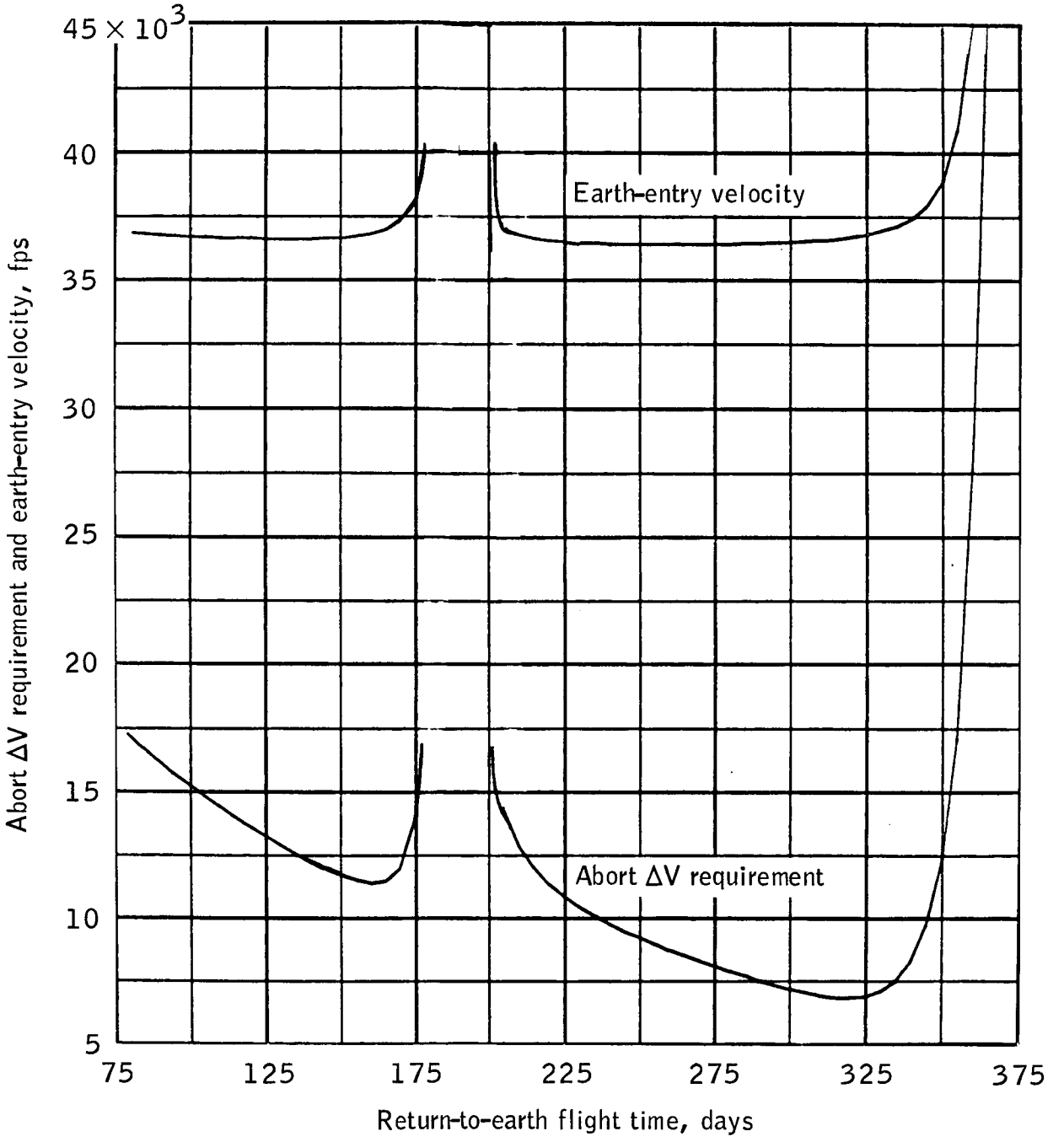

(d) Elapsed time to abort is 20 days after TMI.

Figure 8.- Continued.



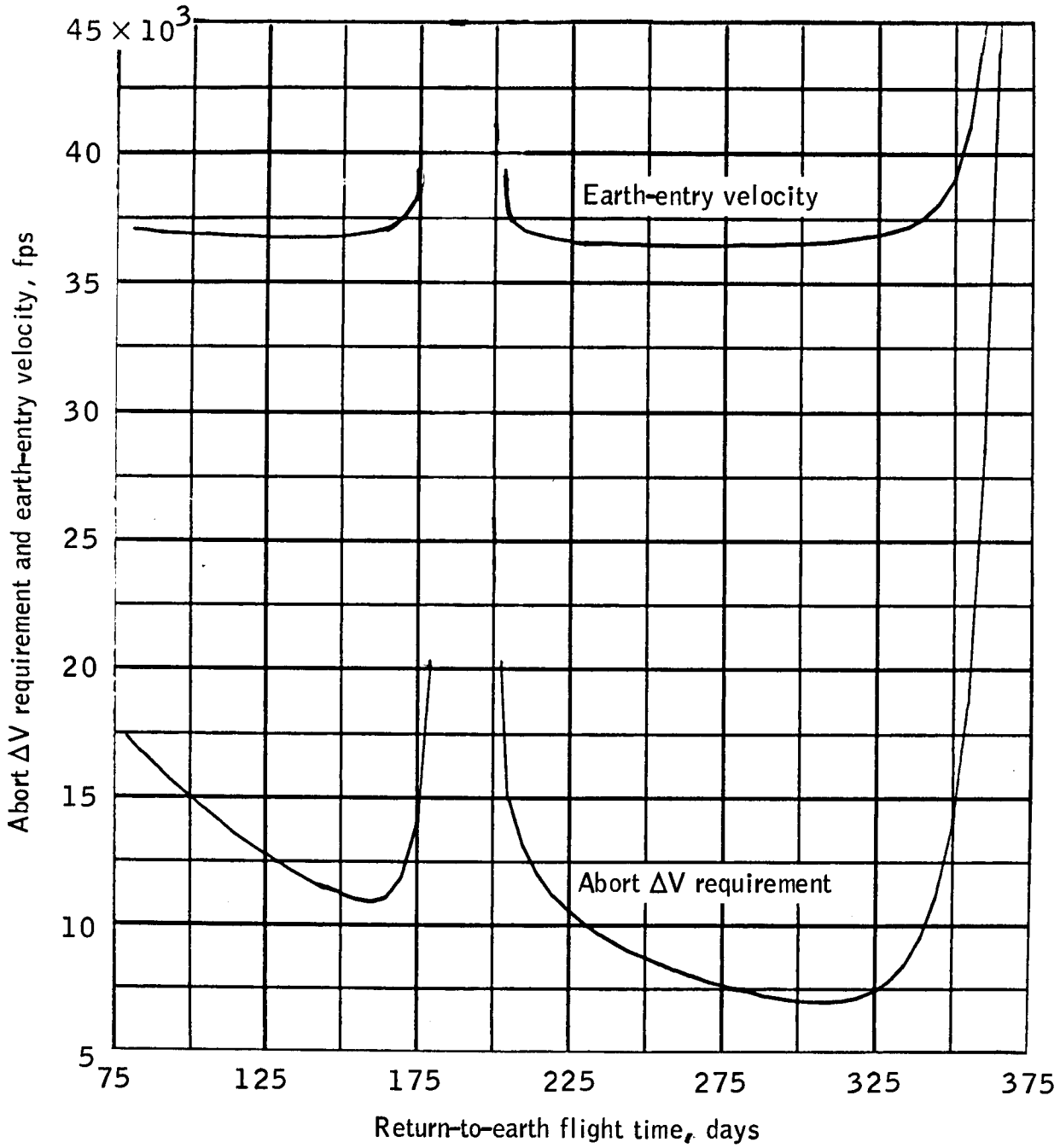

(e) Elapsed time to abort is 25 days after TMI.

Figure 8. - Continued.



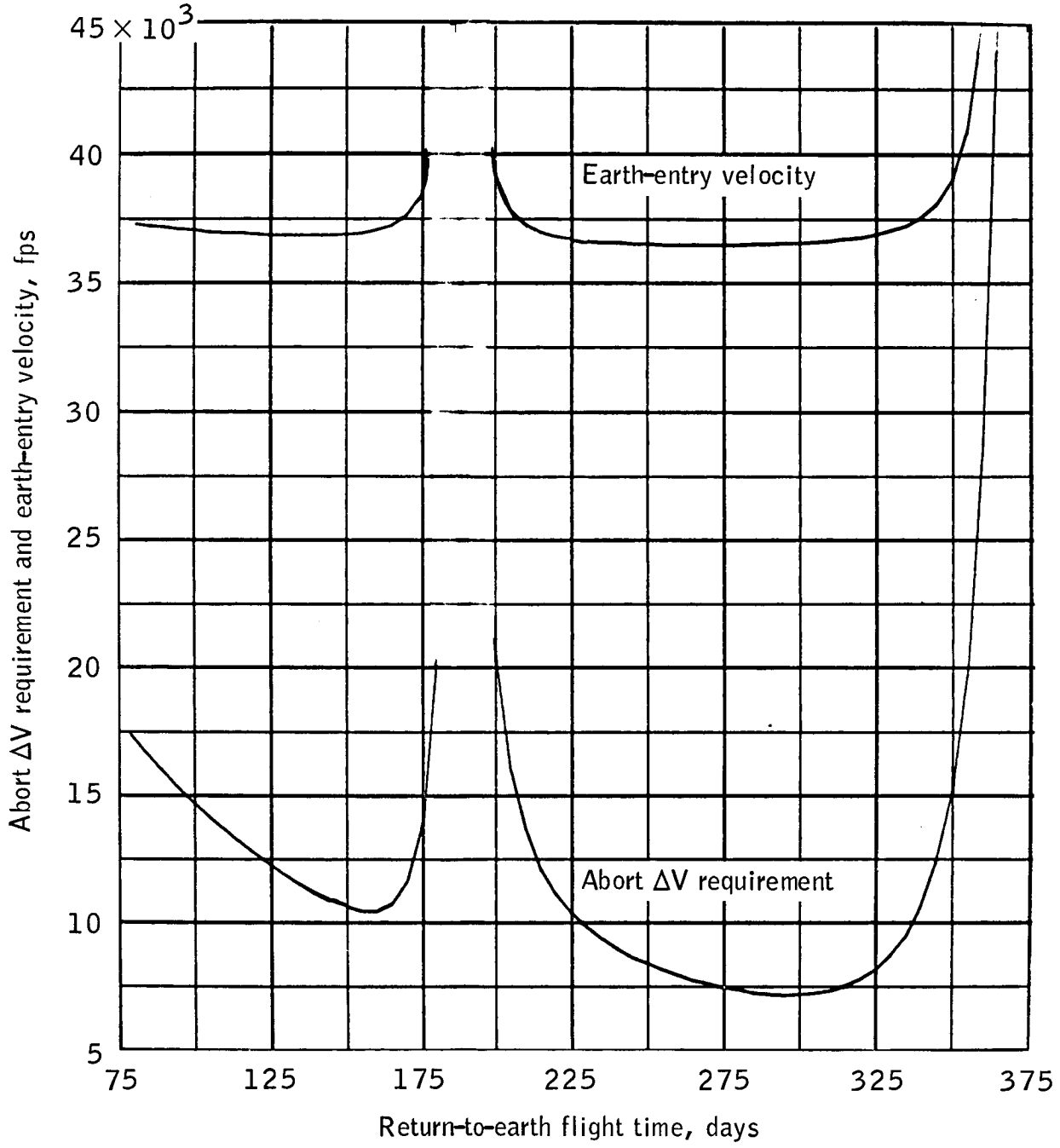

(f) Elapsed time to abort is 30 days after TMI.

Figure 8.- Continued.



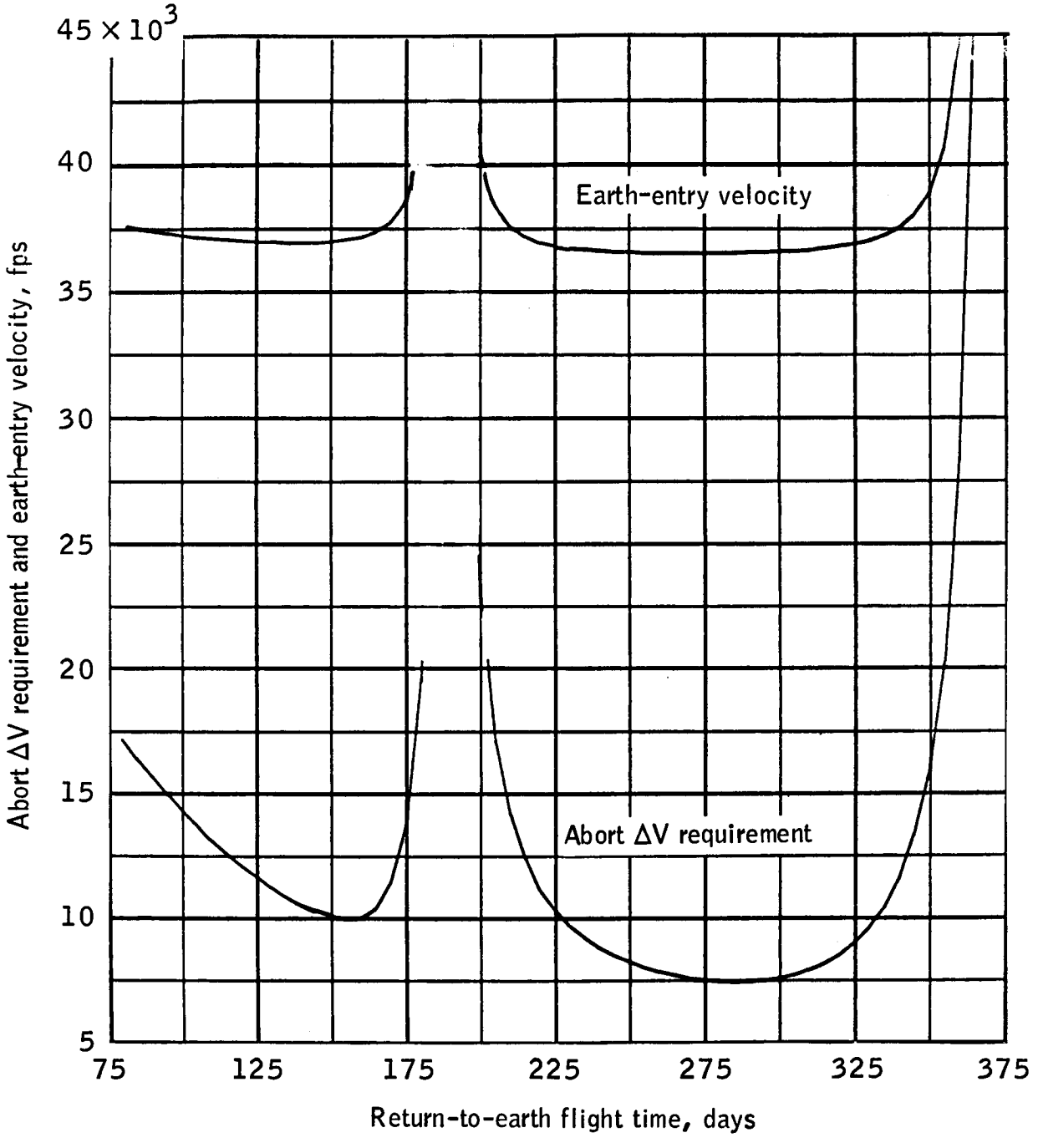

(g) Elapsed time to abort is 35 days after TMI.

Figure 8.- Continued.



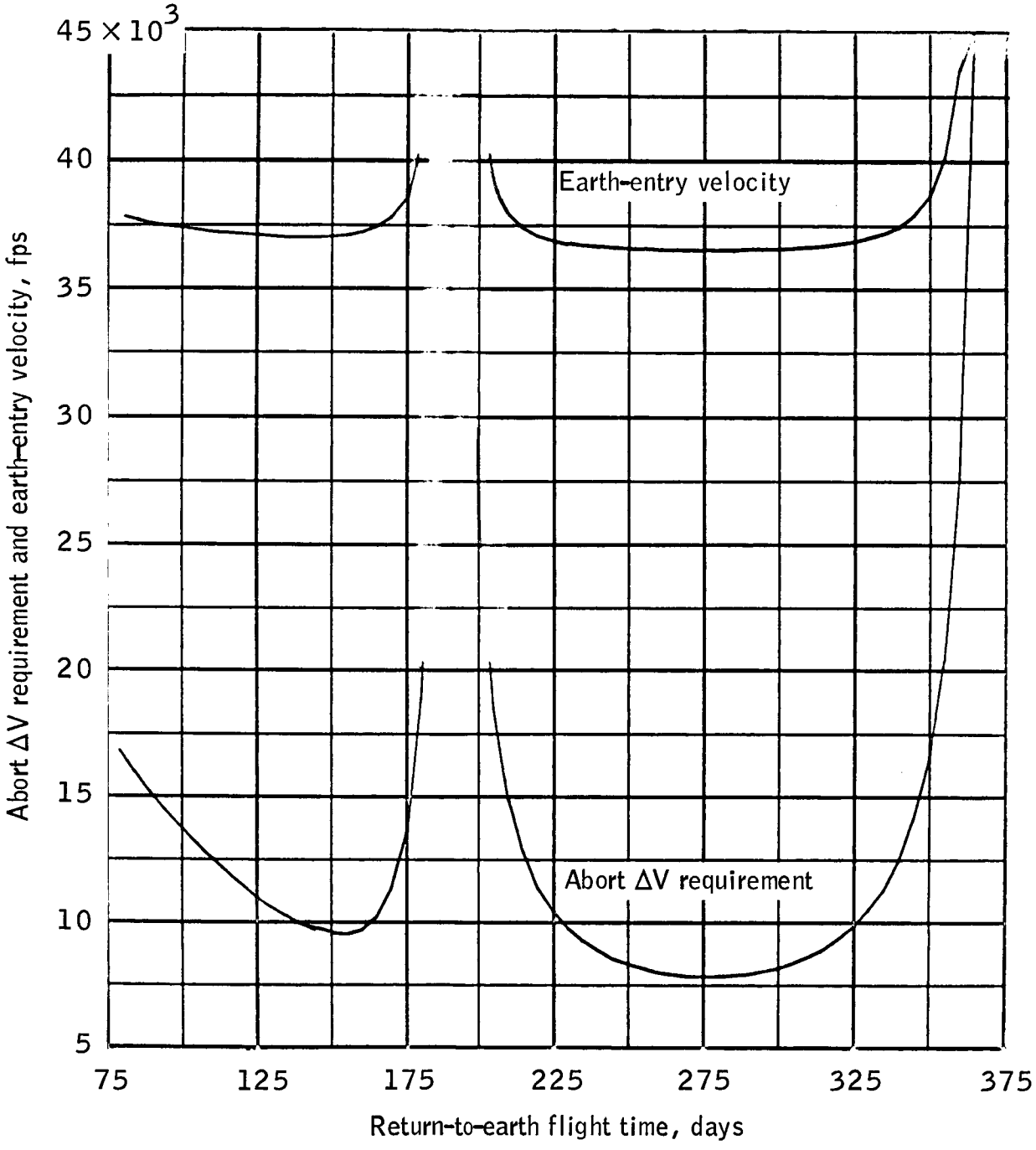

(h) Elapsed time to abort is 40 days after TMI.

Figure 8.- Continued.



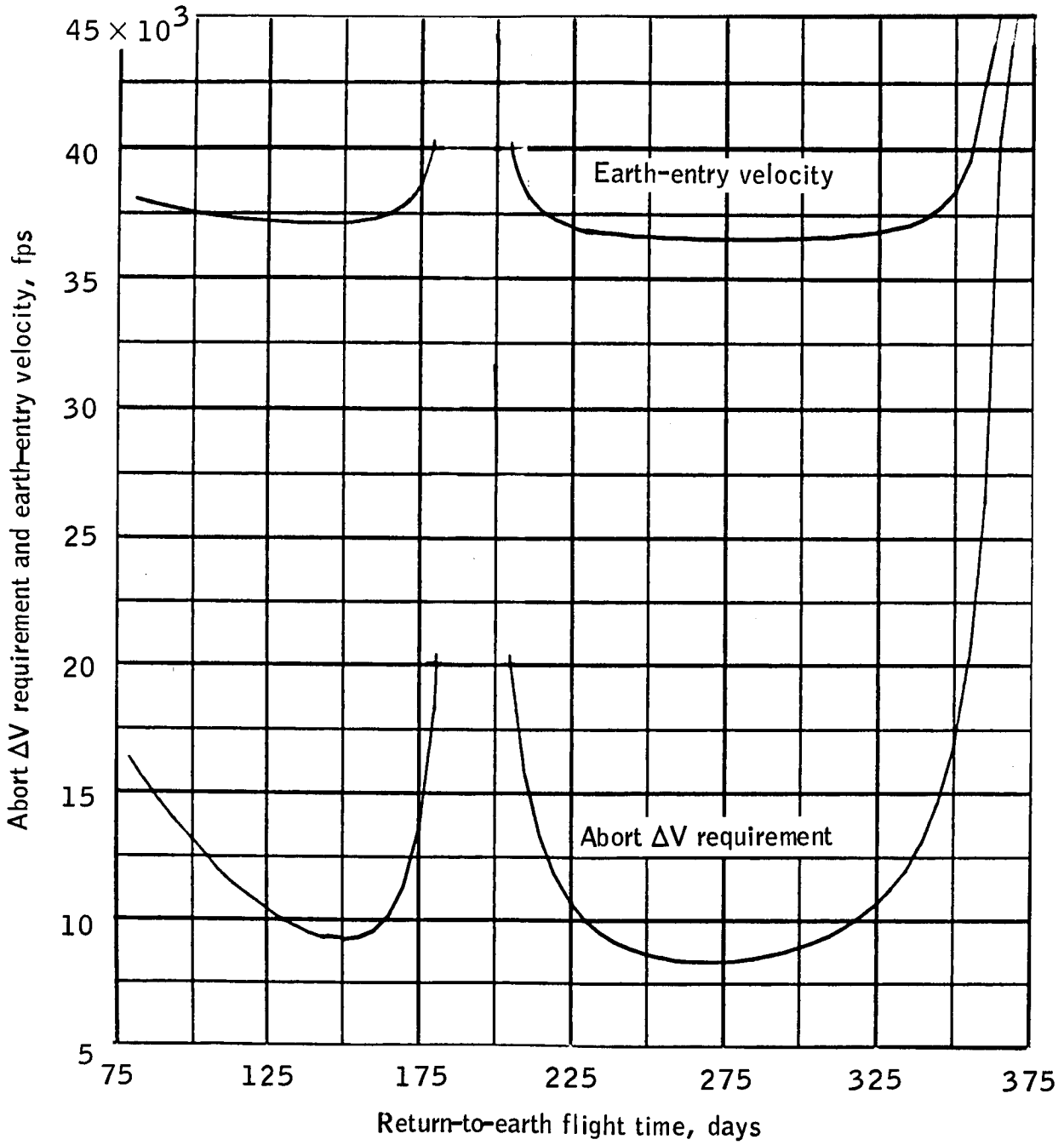

(i) Elapsed time to abort is 45 days after TMI.

Figure 8.- Continued.



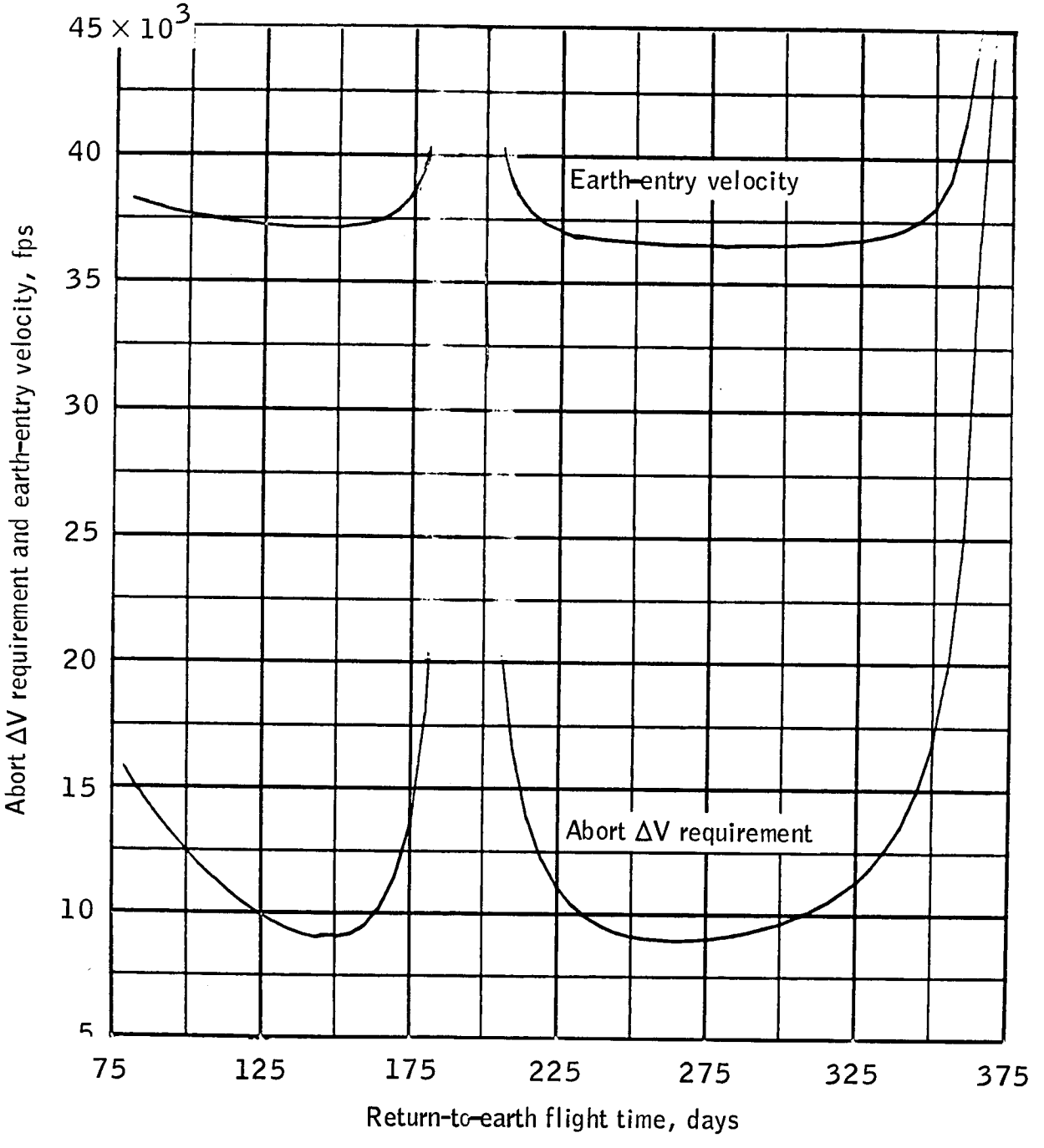

(j) Elapsed time to abort is 60 days after TMI.

Figure 8.- Continued.



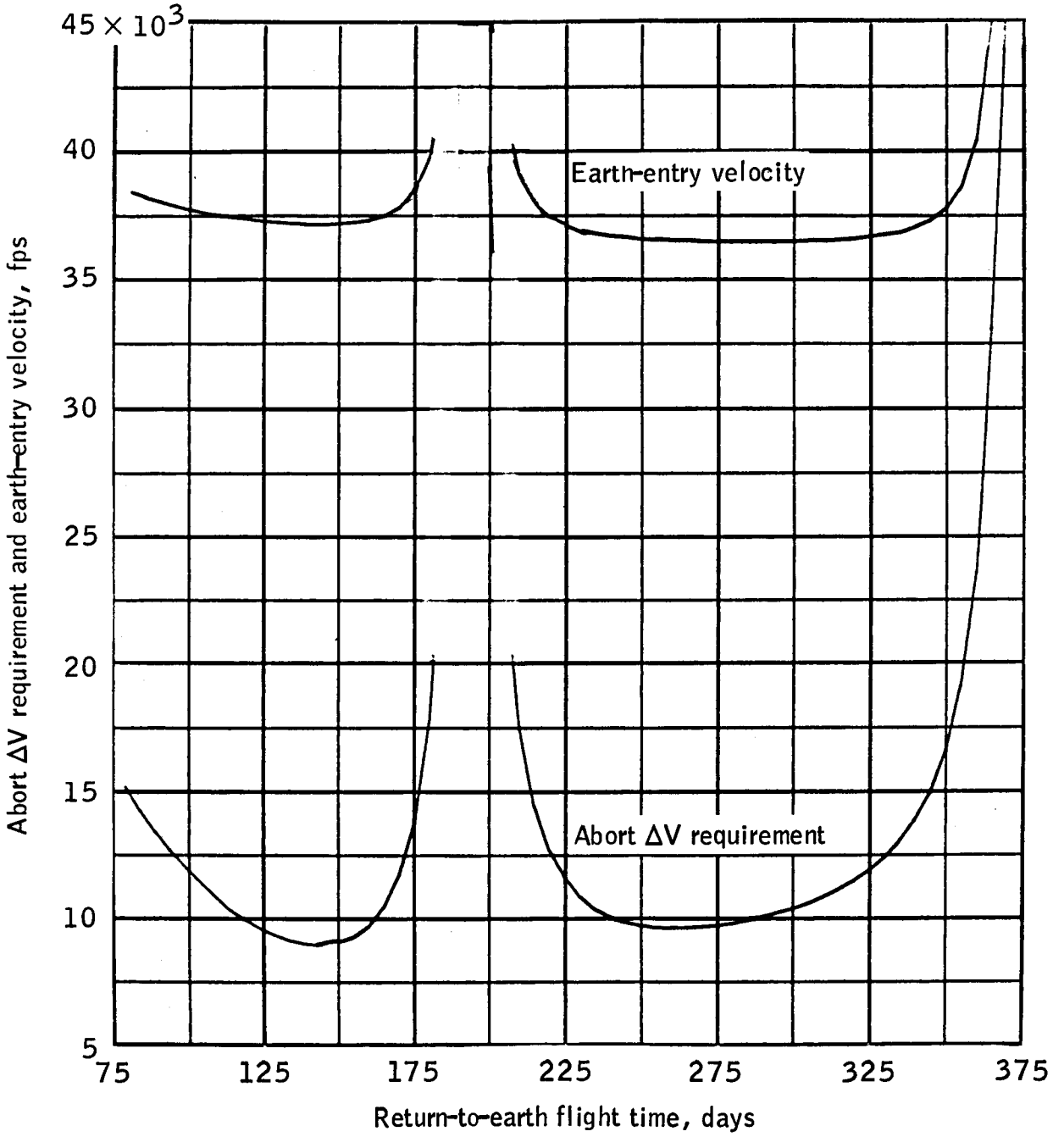

(k) Elapsed time to abort is 55 days after TMI.

Figure 8.- Continued.



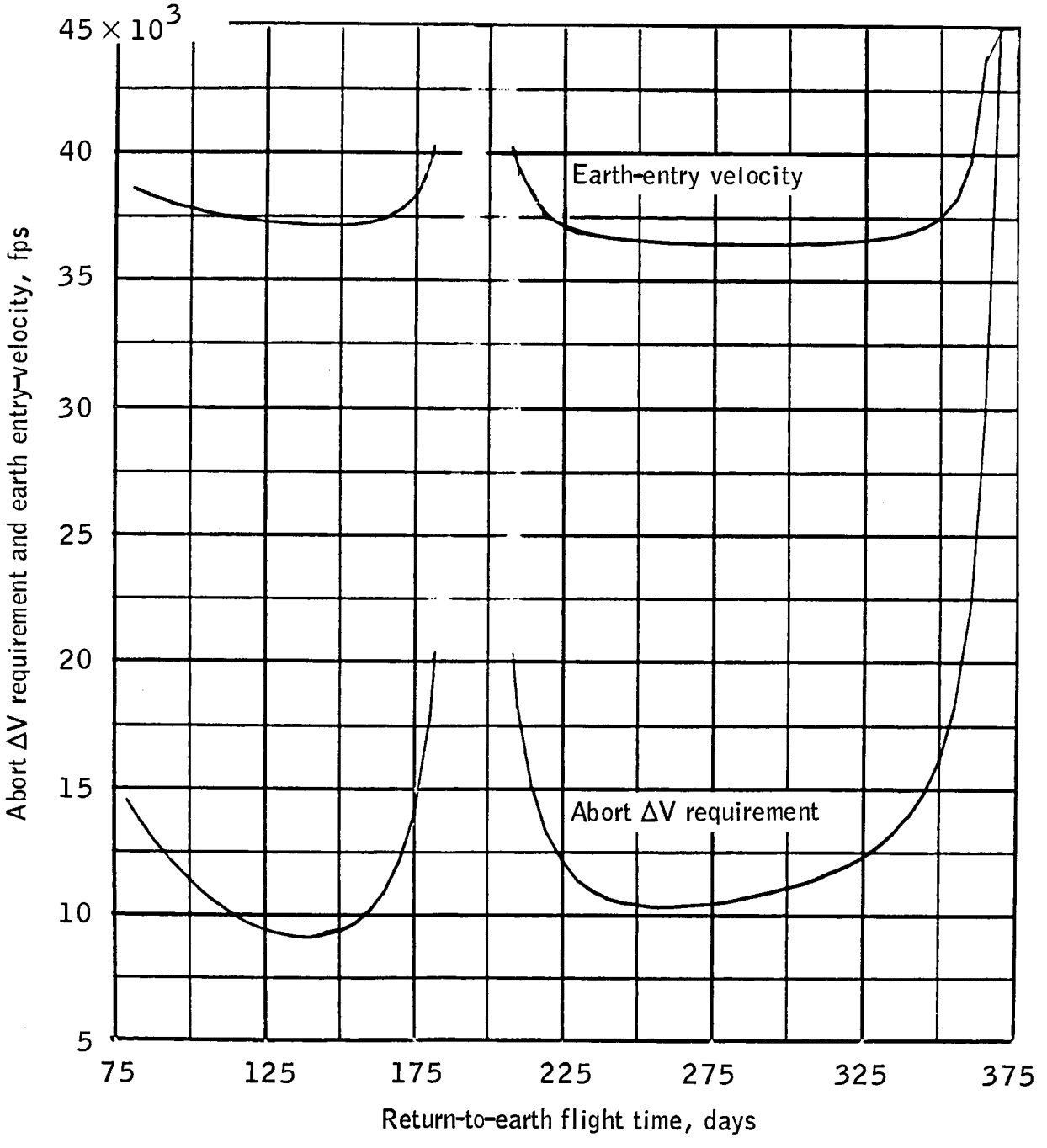

(l) Elapsed time to abort is 60 days after TMI.

Figure 8.- Continued.



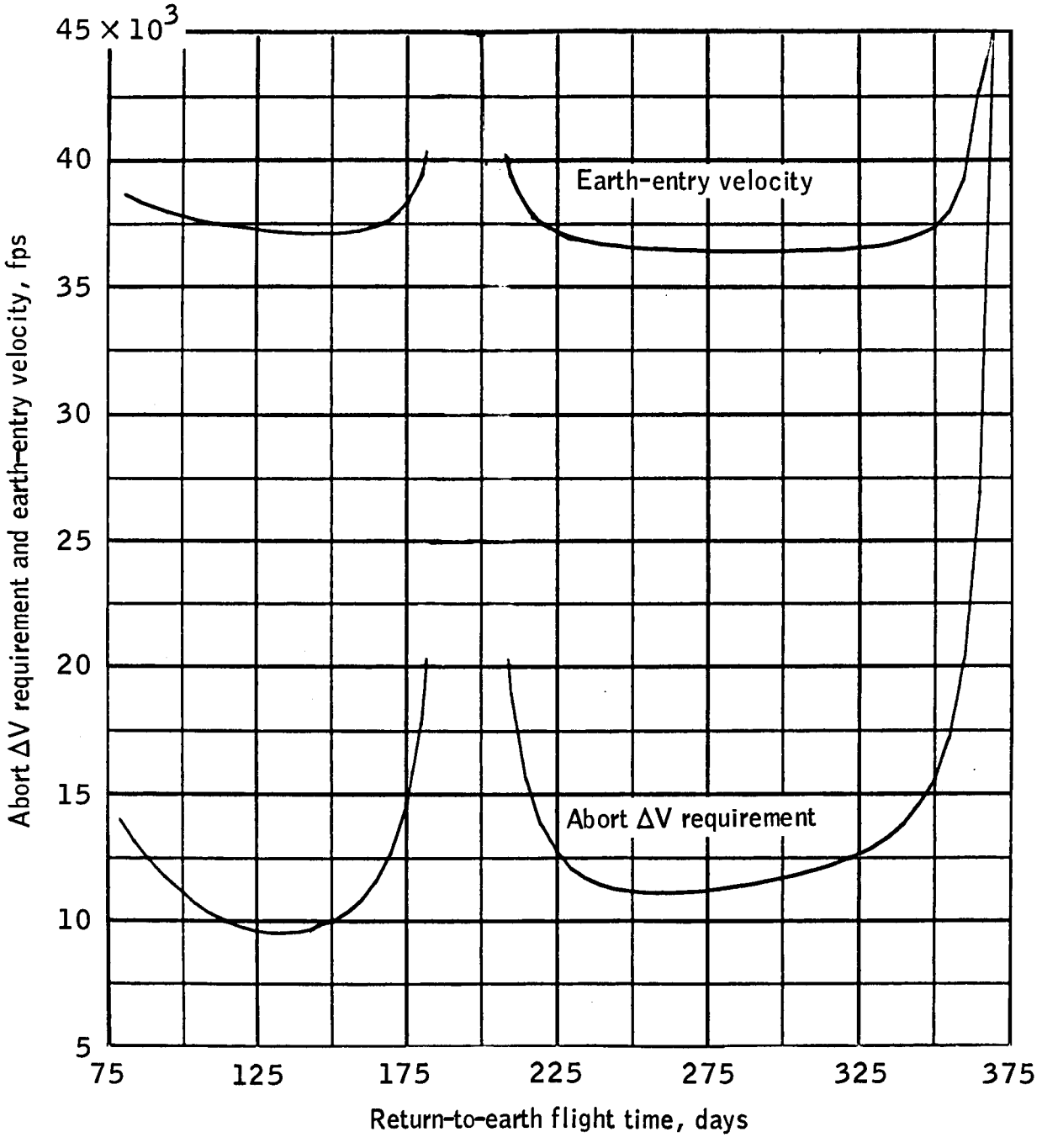

(m) Elapsed time to abort is 65 days after TMI.

Figure 8.- Continued.



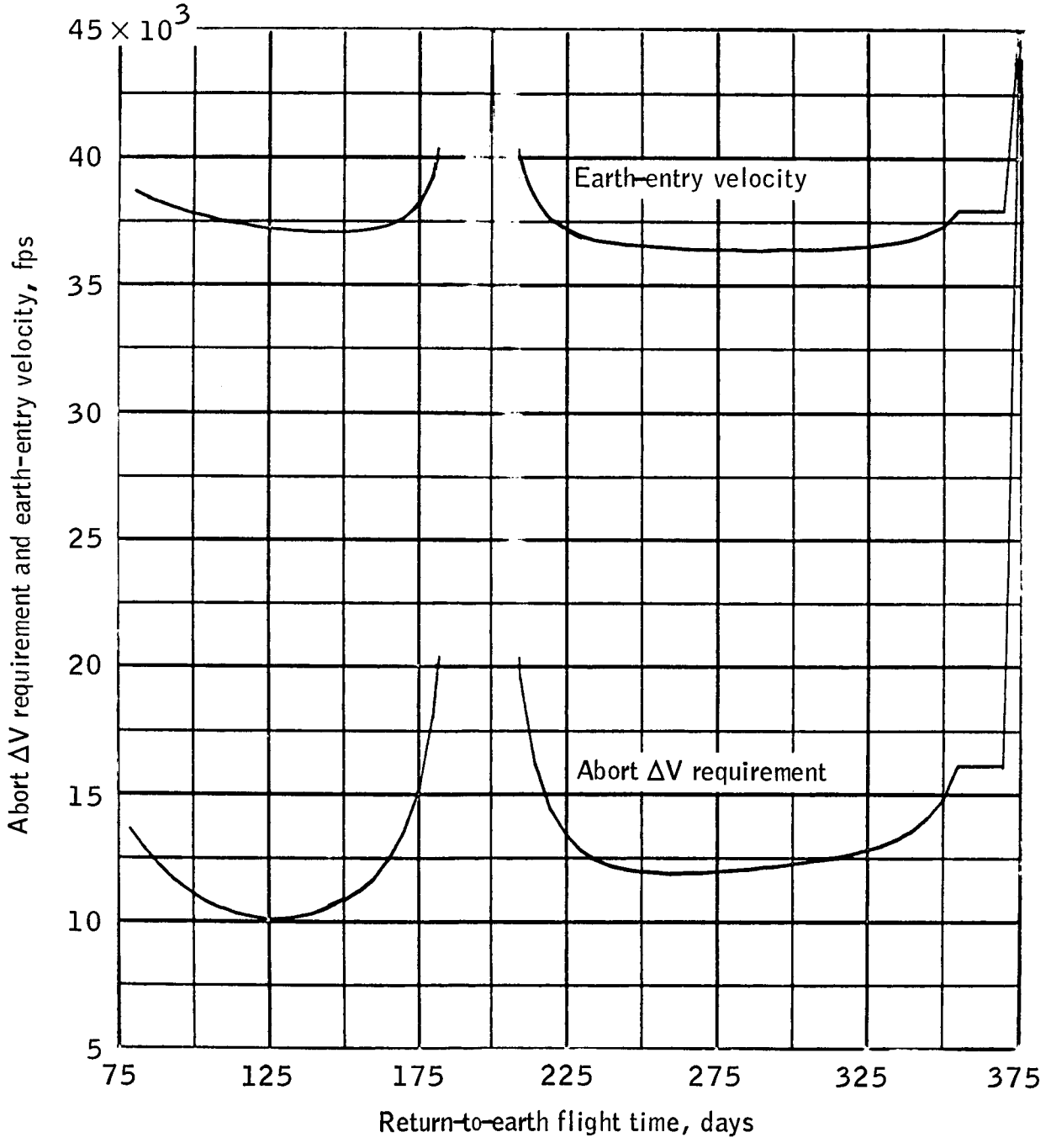

(n) Elapsed time to abort is 70 days after TMI.

Figure 8.- Continued.



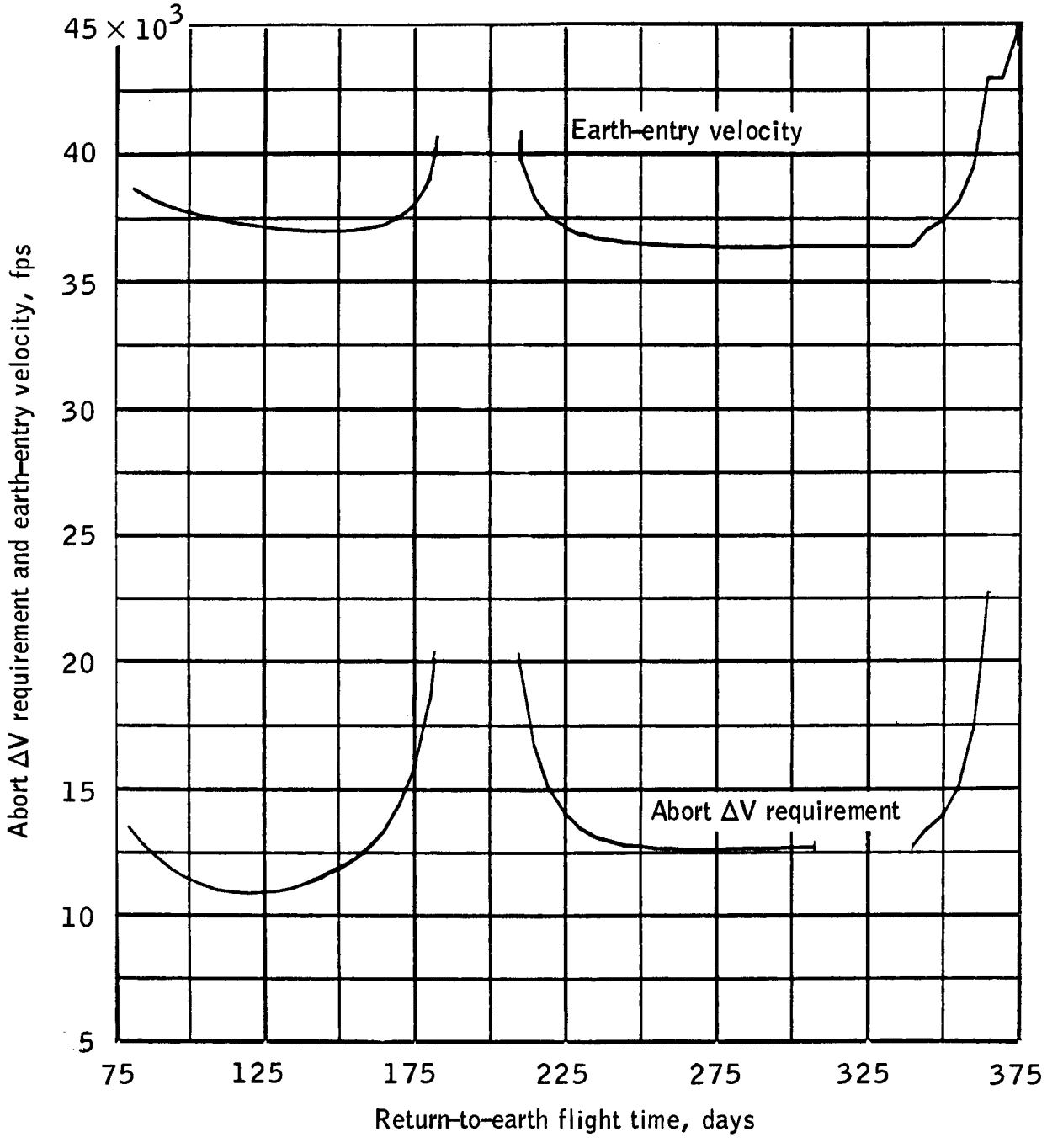

(o) Elapsed time to abort is 75 days after TMI.

Figure 8.- Continued.



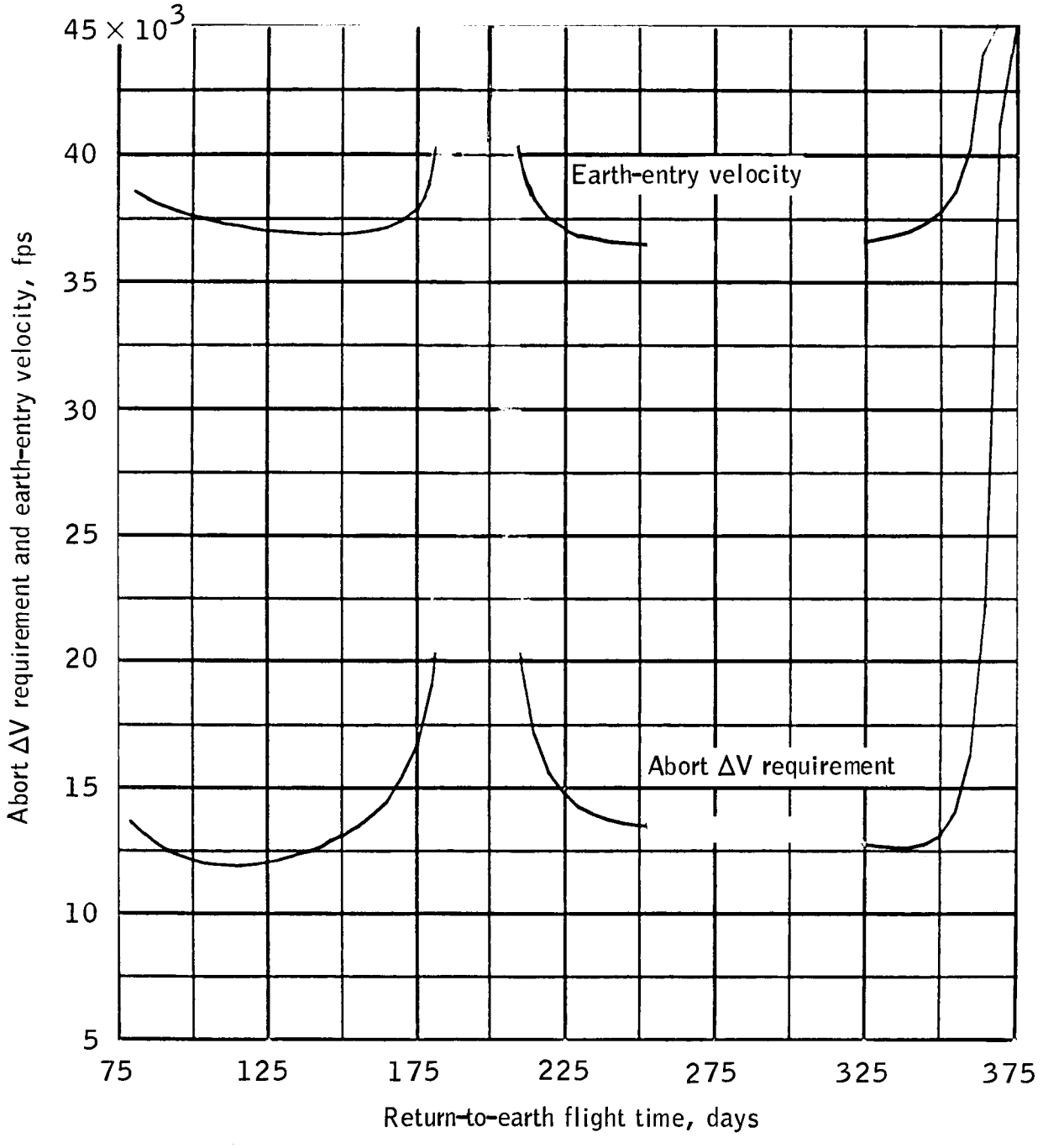

(p) Elapsed time to abort is 80 days after TMI.

Figure 8.- Continued.



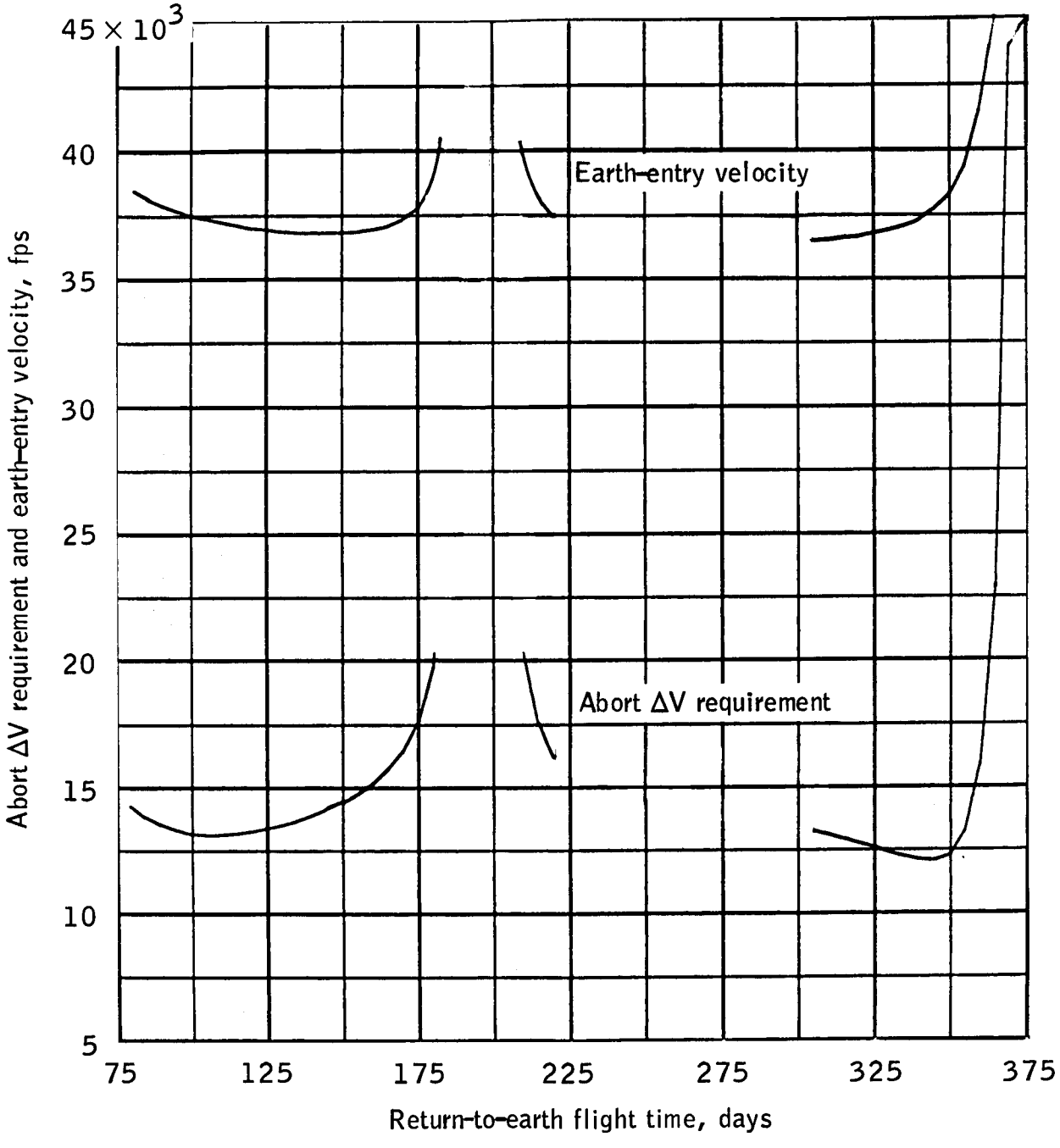

(q) Elapsed time to abort is 85 days after TMI.

Figure 8.- Continued.



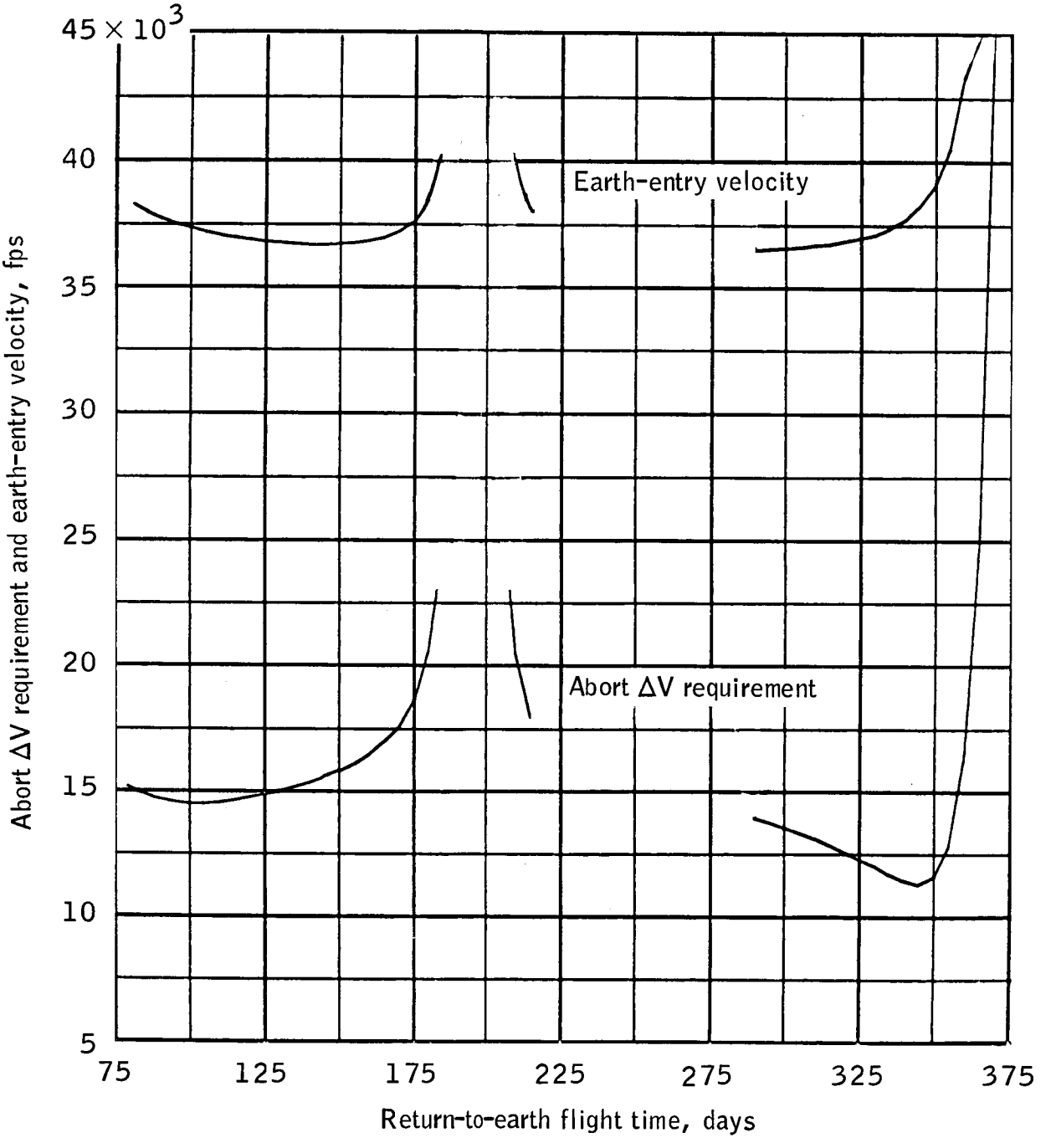

(r) Elapsed time to abort is 90 days after TMI.

Figure 8.- Continued.



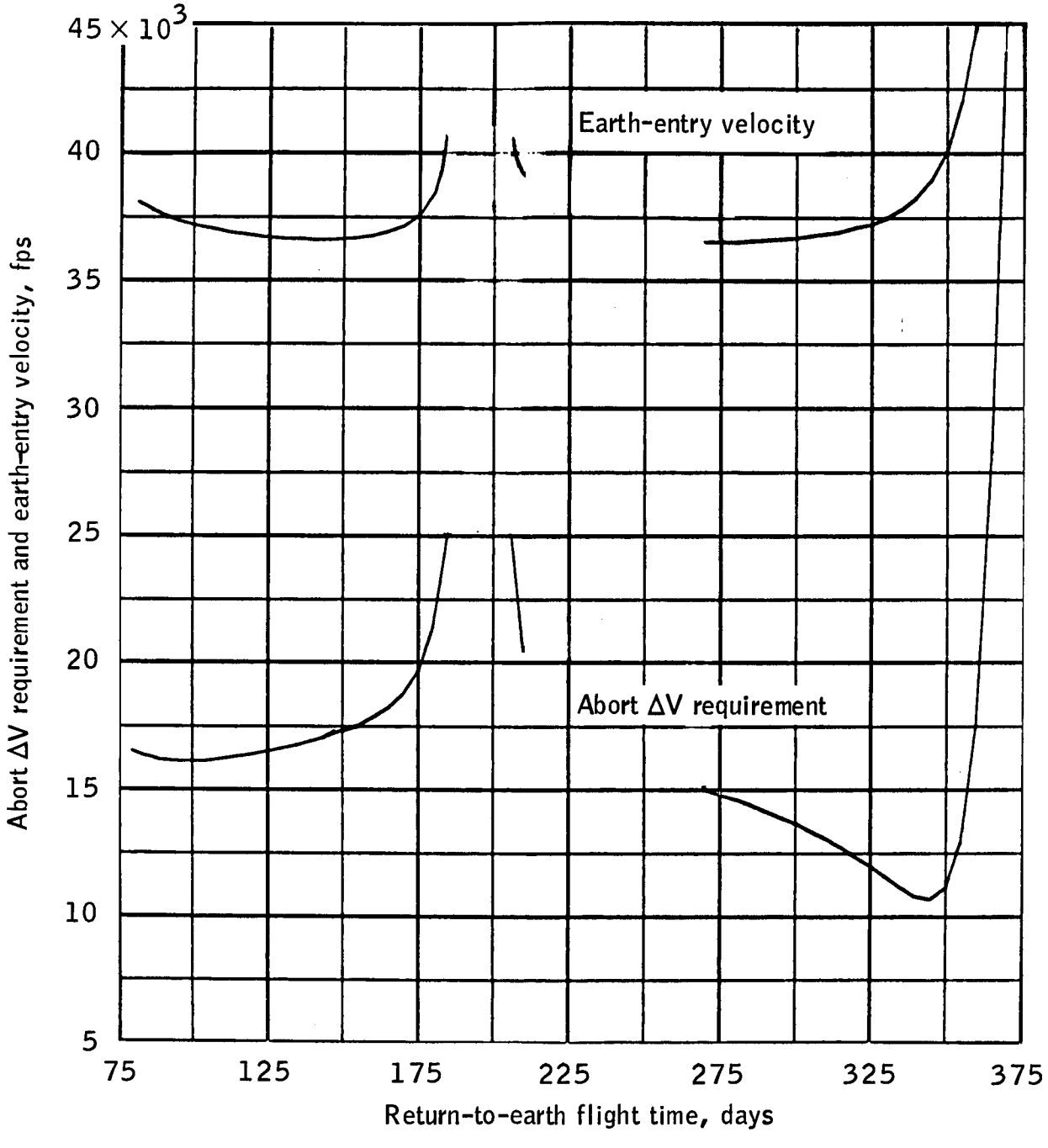

(s) Elapsed time to abort is 95 days after TMI.

Figure 8.- Continued.



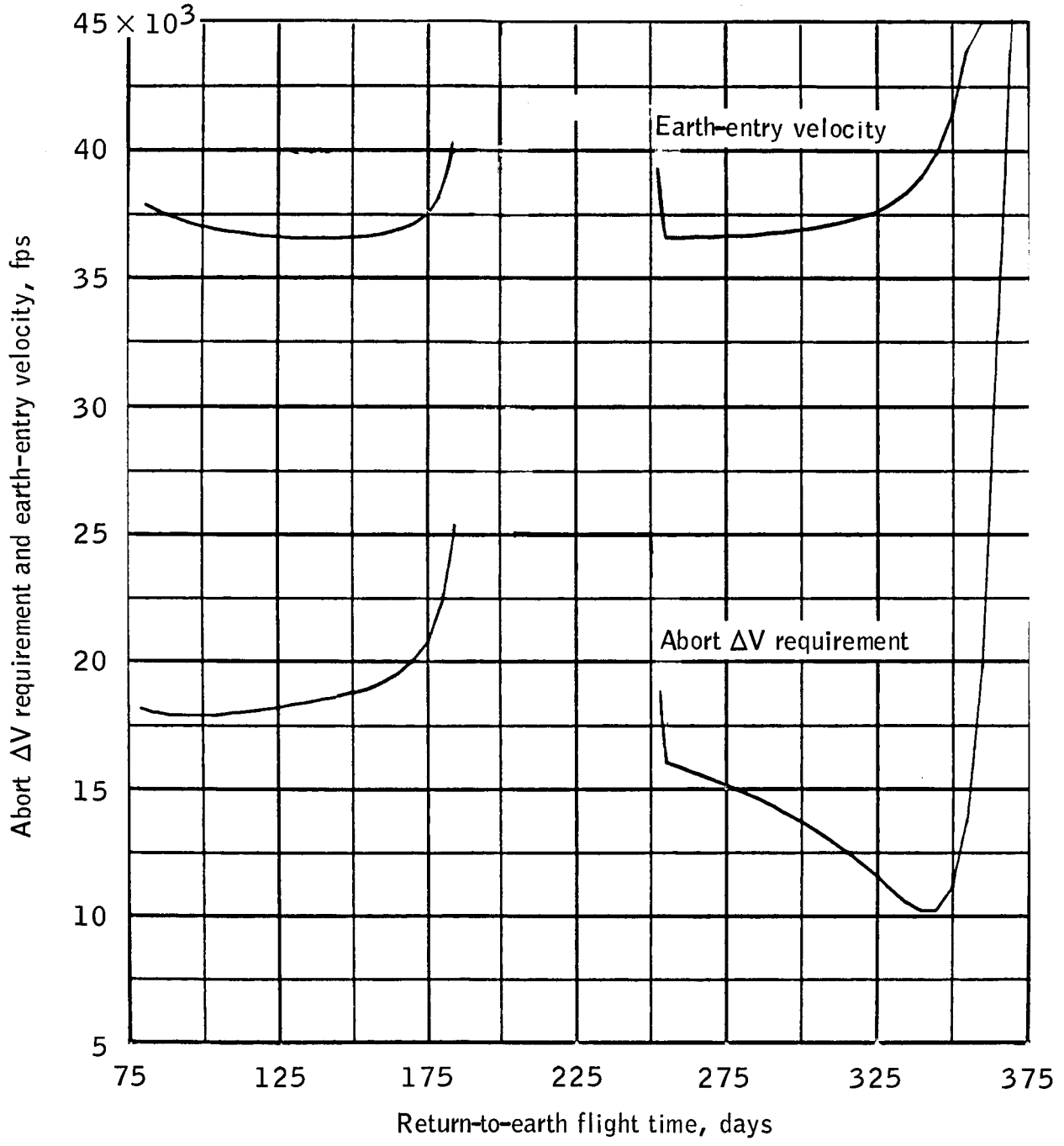

(t) Elapsed time to abort is 100 days after TMI.

Figure 8.- Continued.



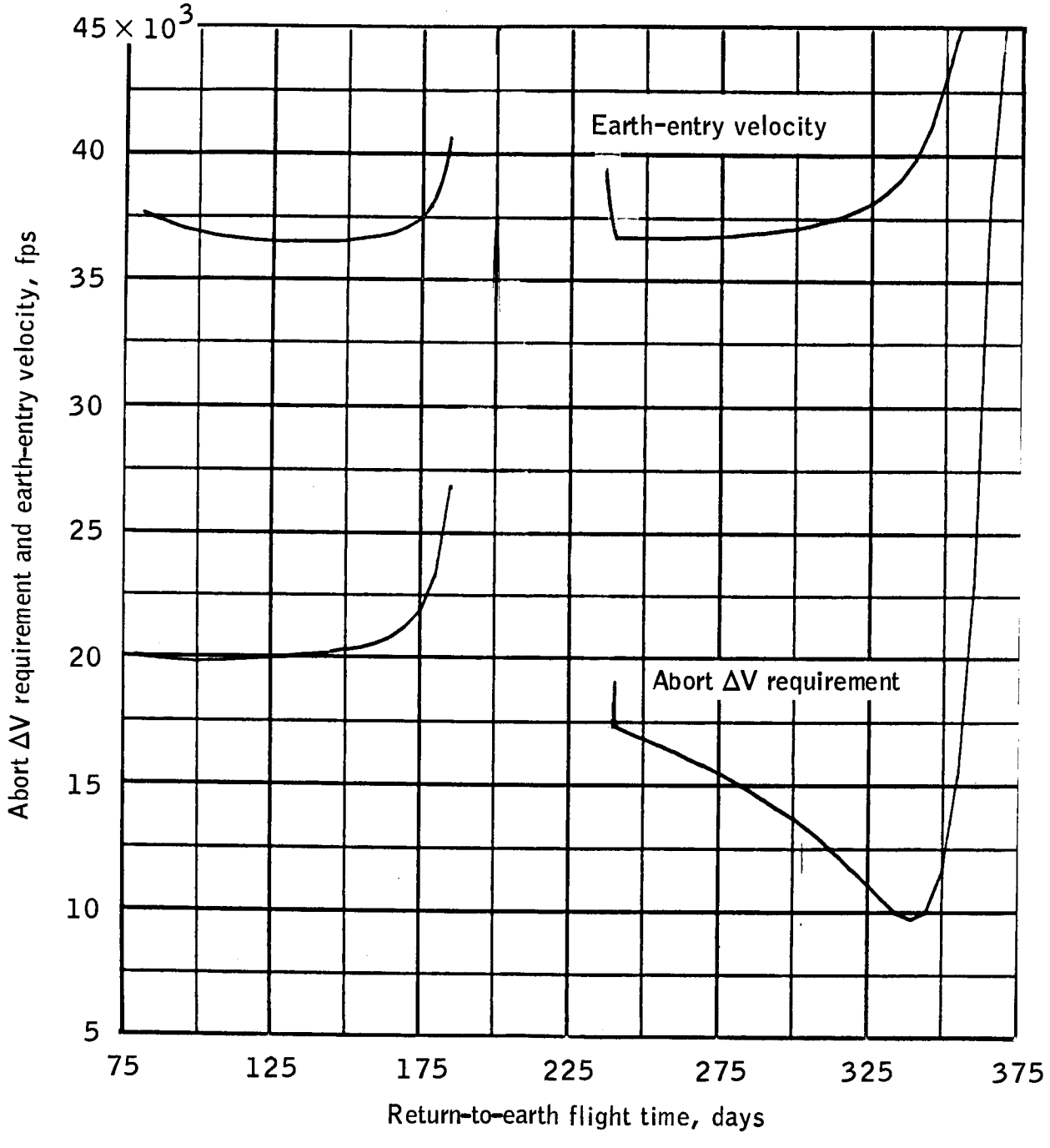

(u) Elapsed time to abort is 105 days after TMI.

Figure 8.- Continued.



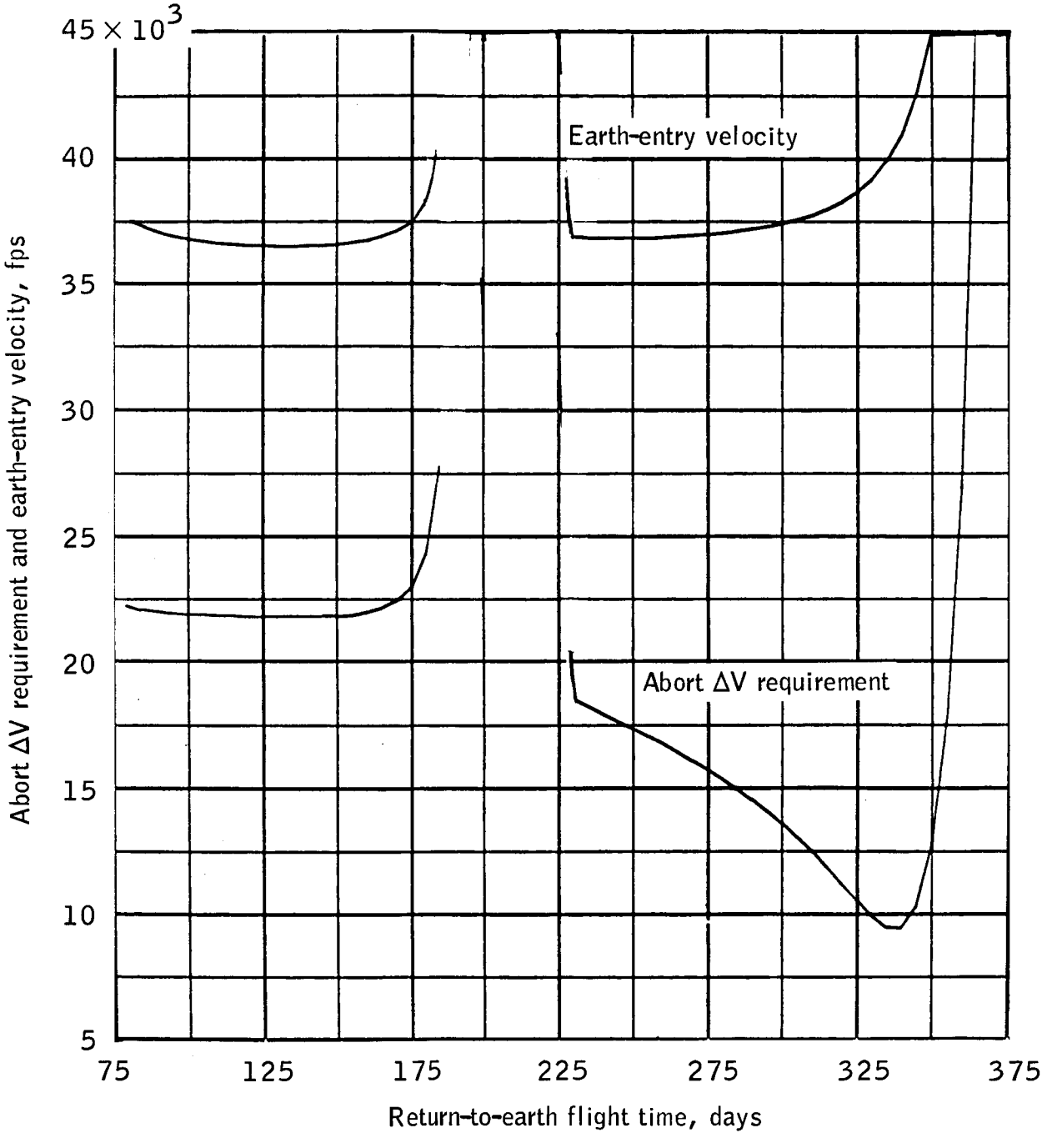

(v) Elapsed time to abort is 110 days after TMI.

Figure 8.- Continued.



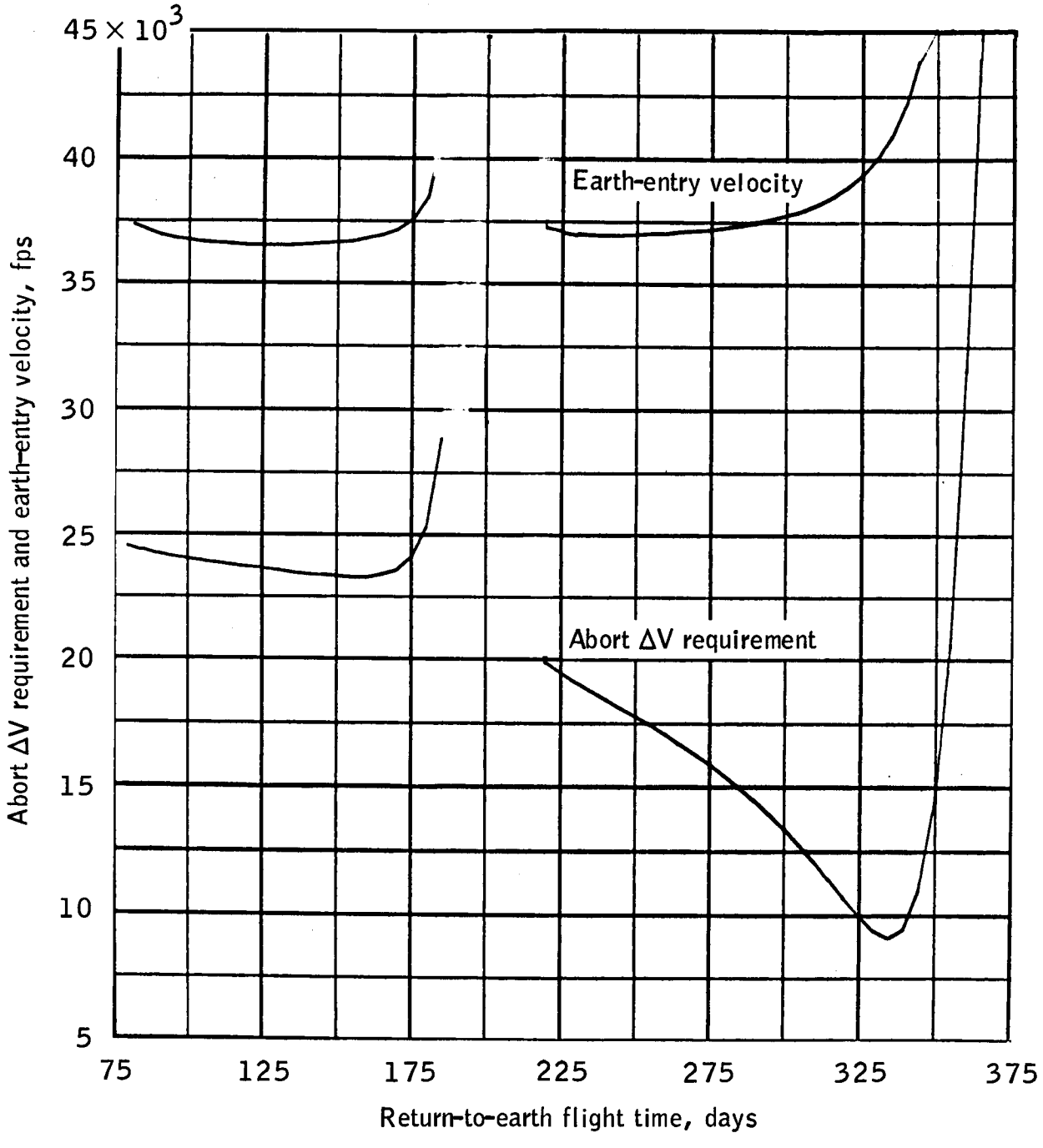

(w) Elapsed time to abort is 115 days after TMI.

Figure 8.- Continued.



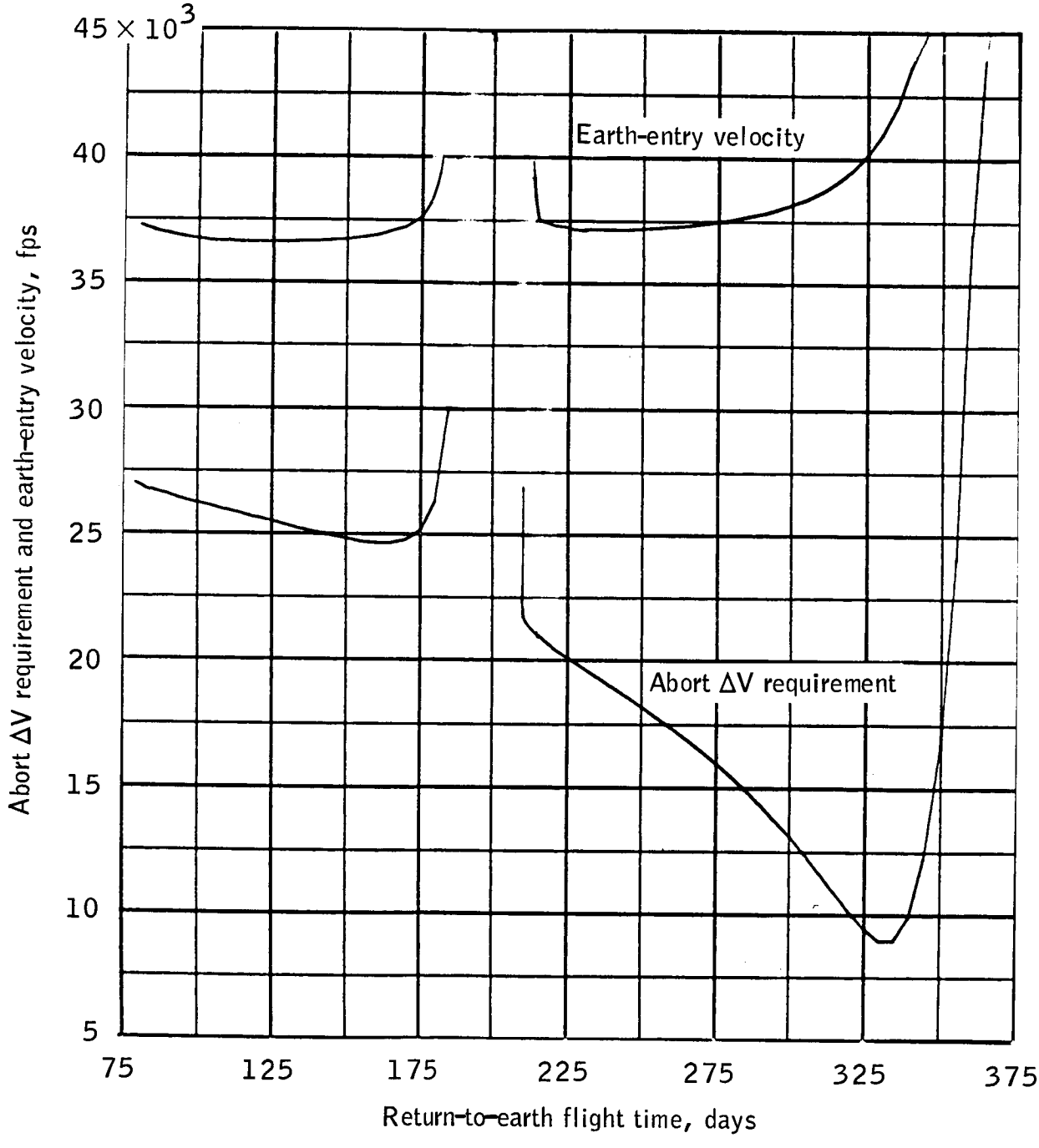

(x) Elapsed time to abort is 120 days after TMI.

Figure 8.- Continued.



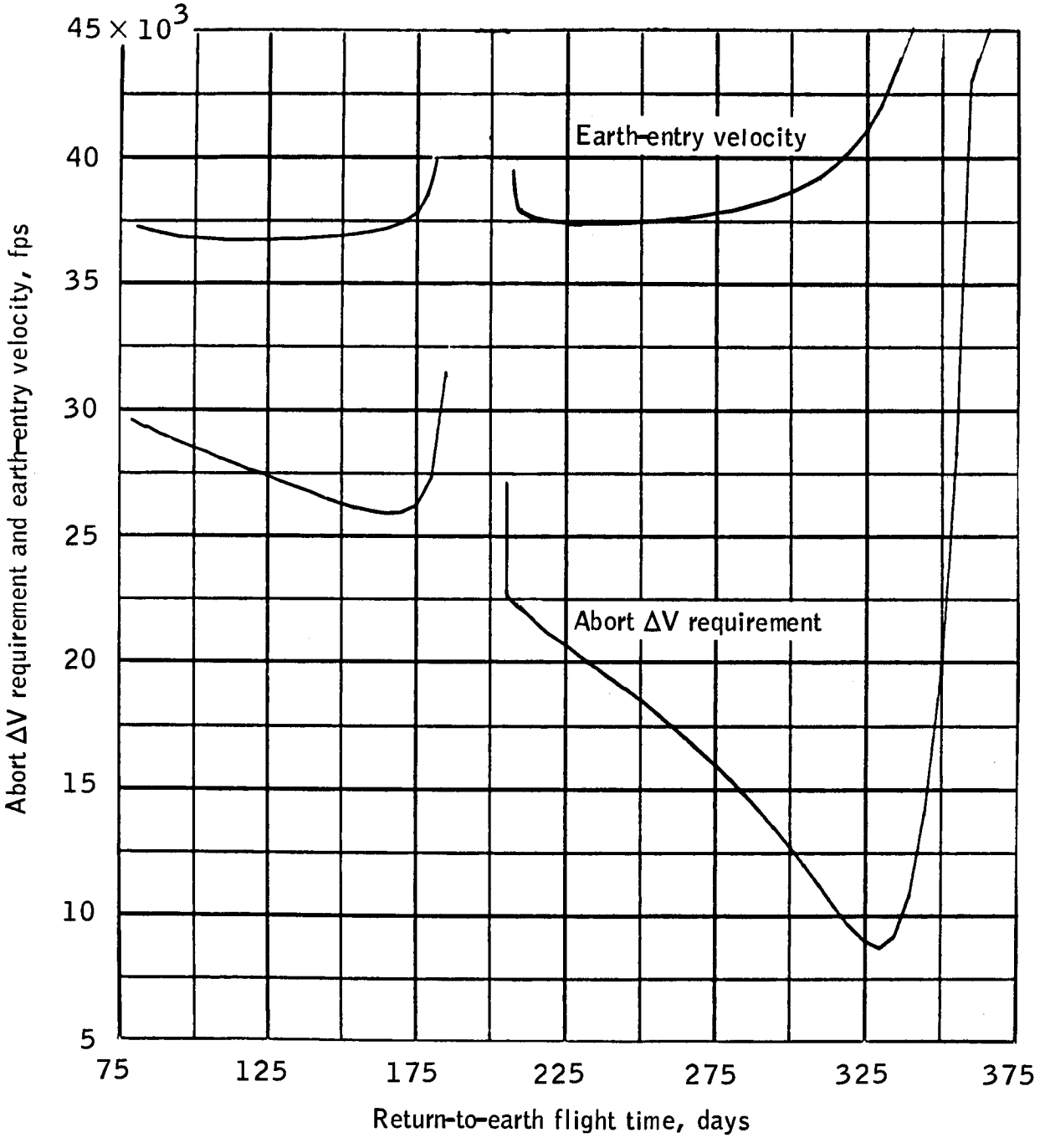

(y) Elapsed time to abort is 125 days after TMI.

Figure 8.- Continued.



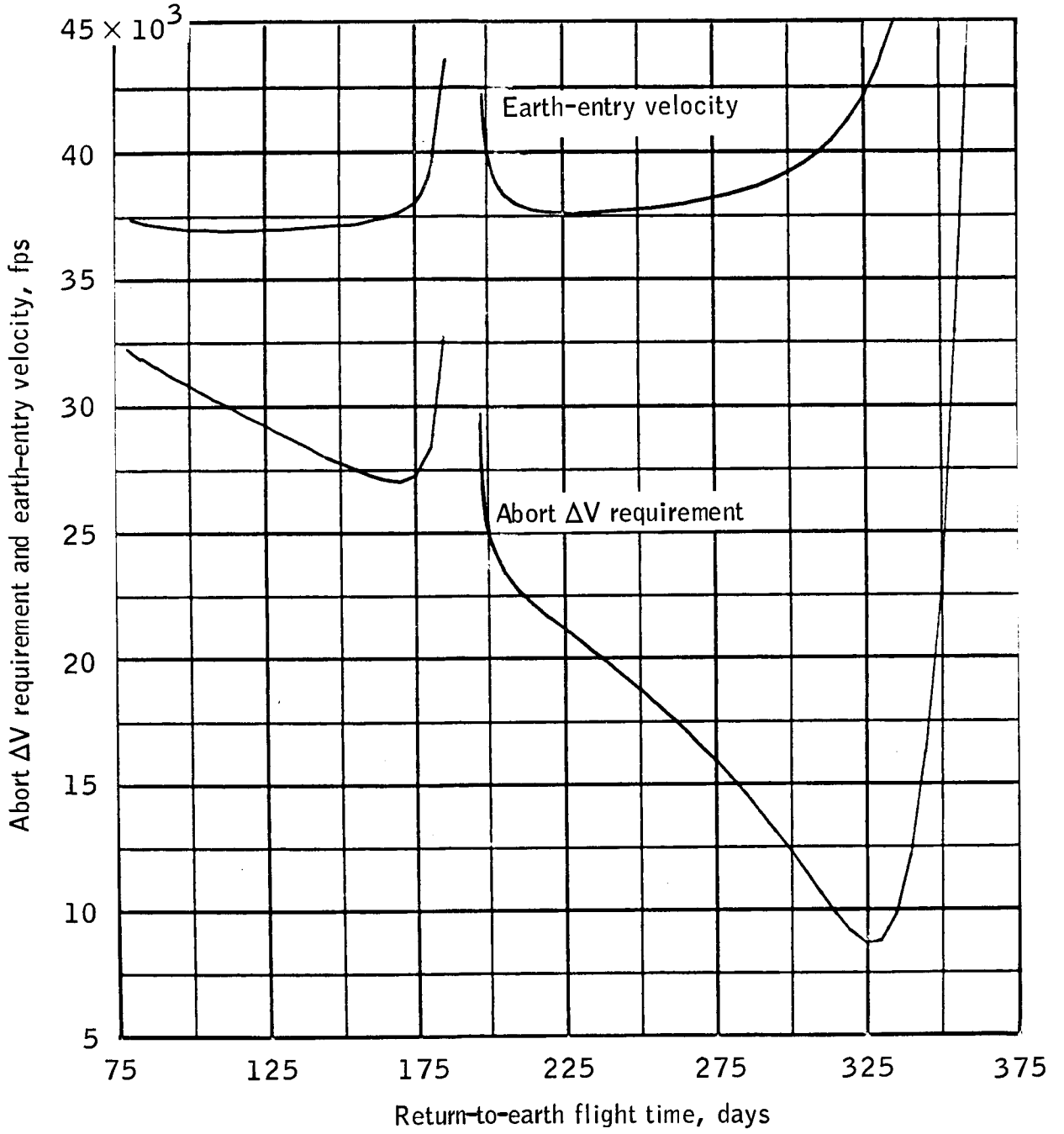

(z) Elapsed time to abort is 130 days after TMI.

Figure 8.- Continued.



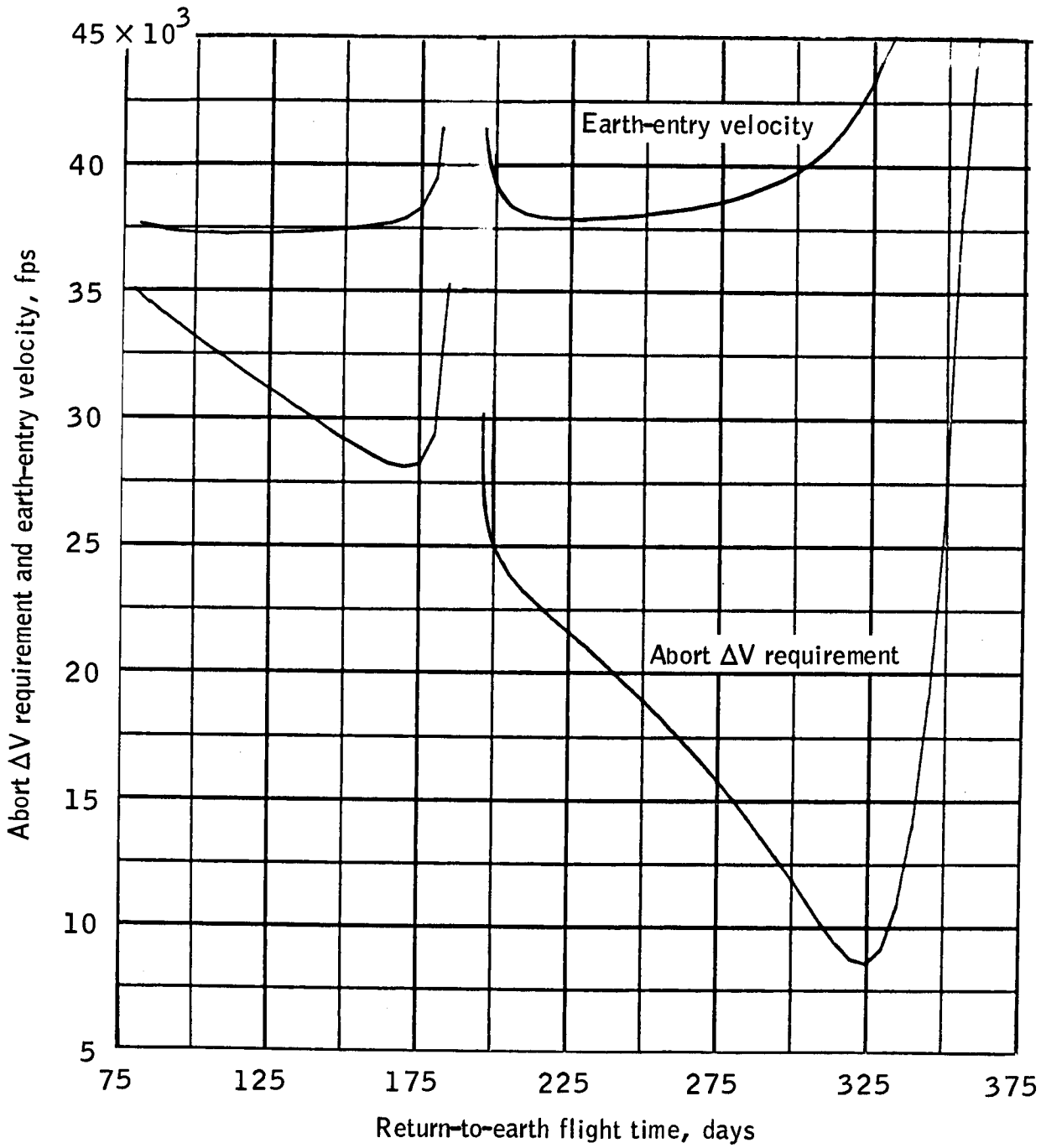

(aa) Elapsed time to abort is 135 days after TMI.

Figure 8.- Continued.



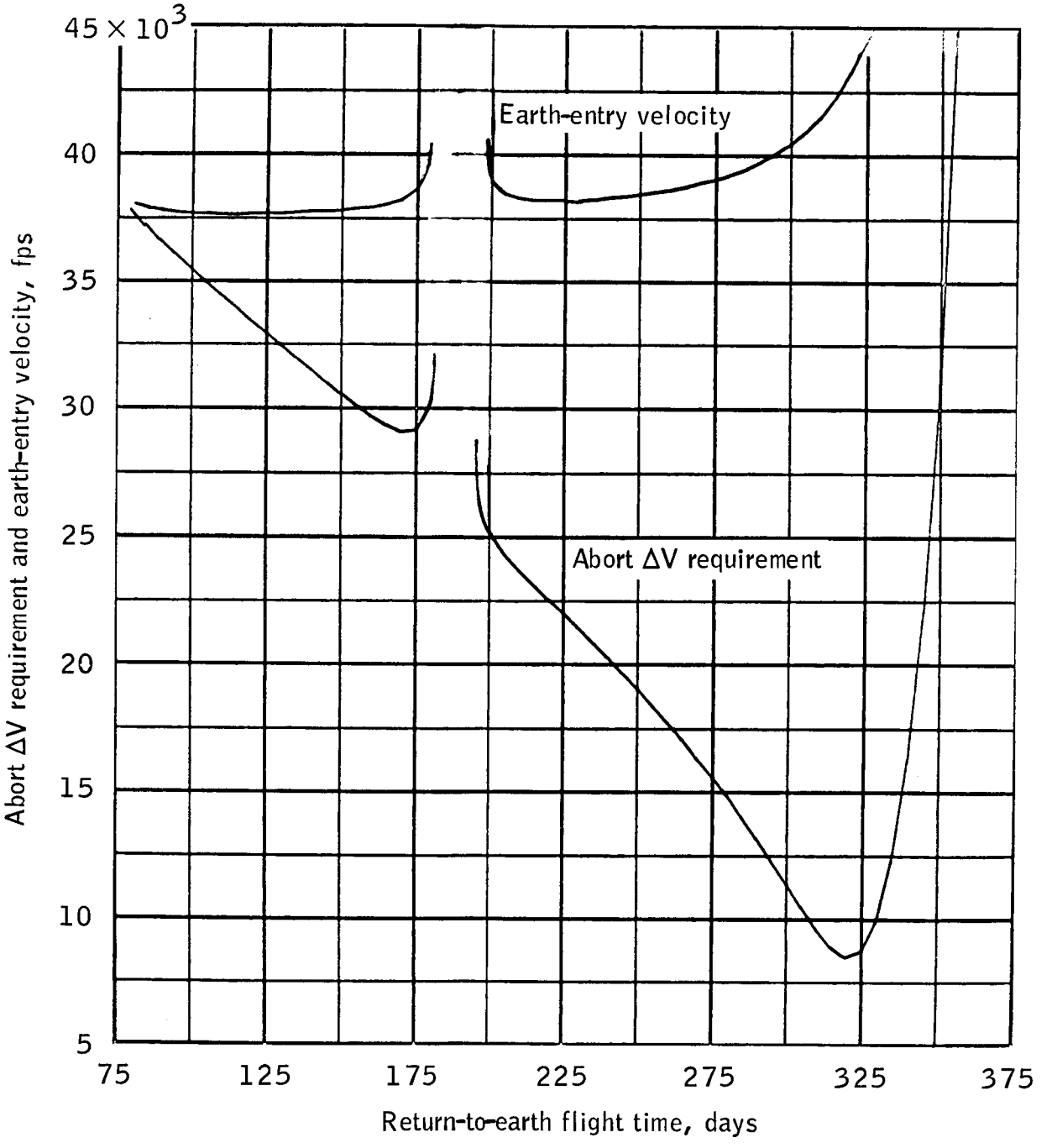

(bb) Elapsed time to abort is 140 days after TMI.

Figure 8.- Continued.



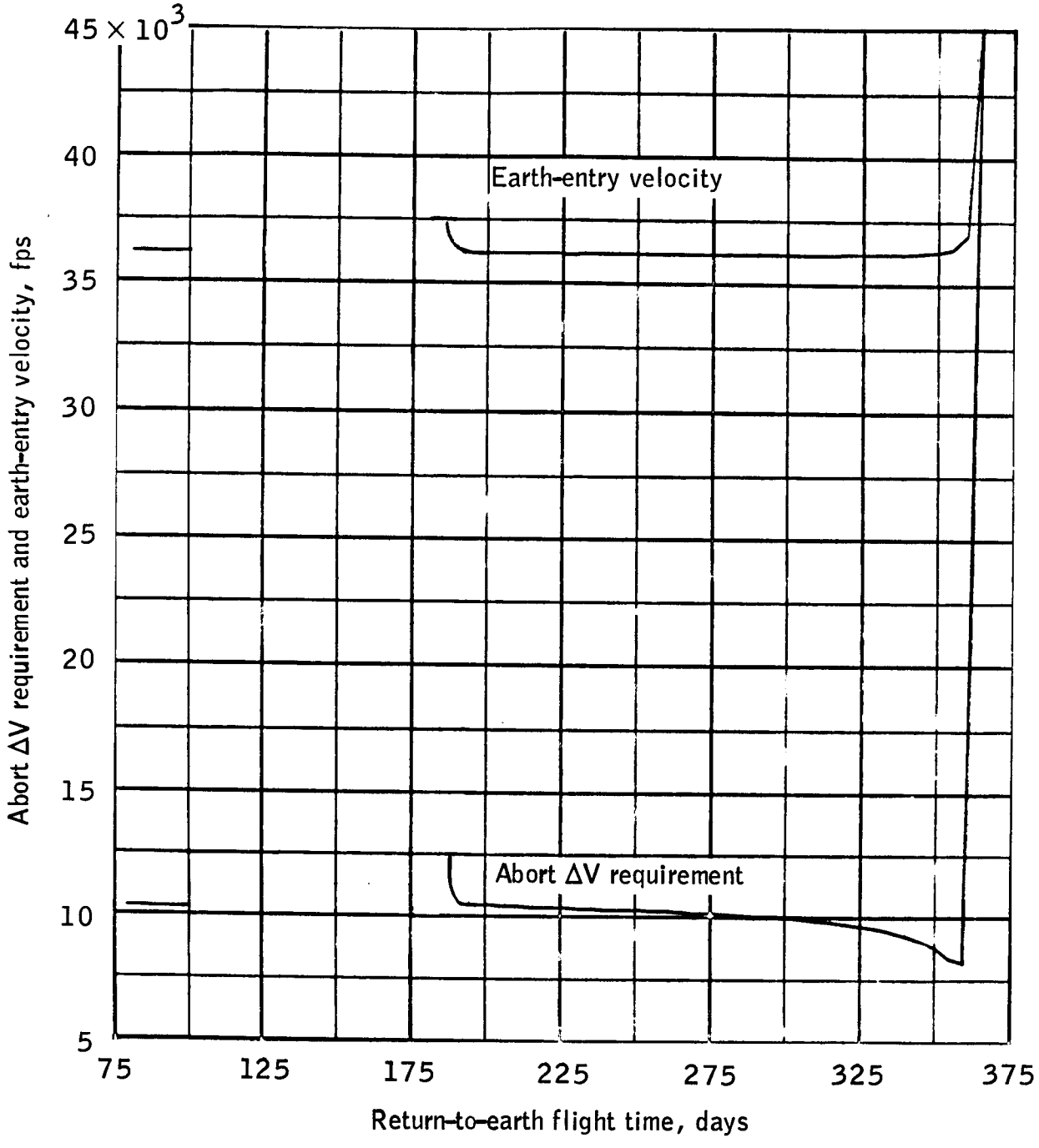

(cc) Elapsed time to abort is 145 days after TMI.

Figure 8.- Continued.



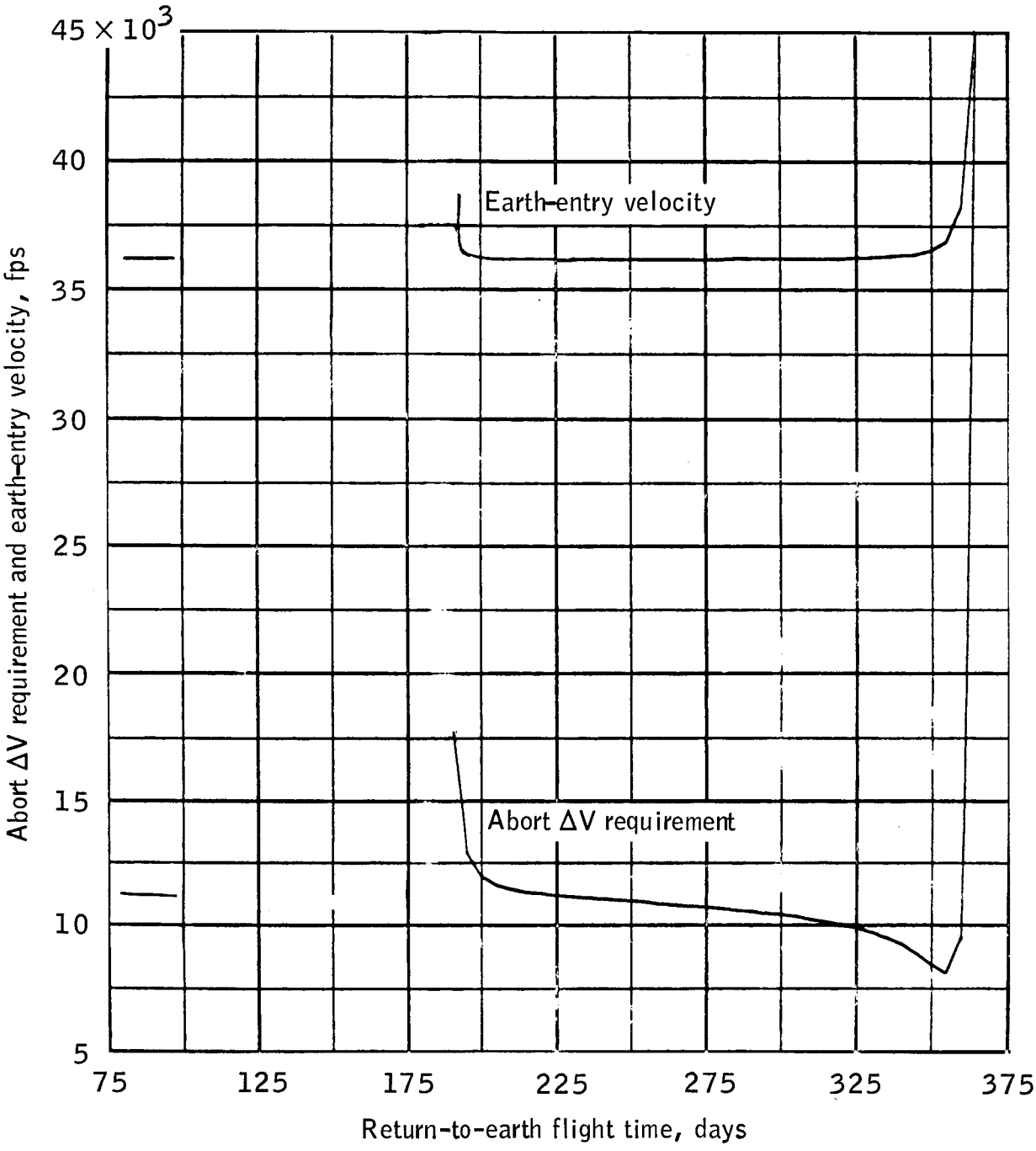

(dd) Elapsed time to abort is 150 days after TMI.

Figure 8.- Concluded.



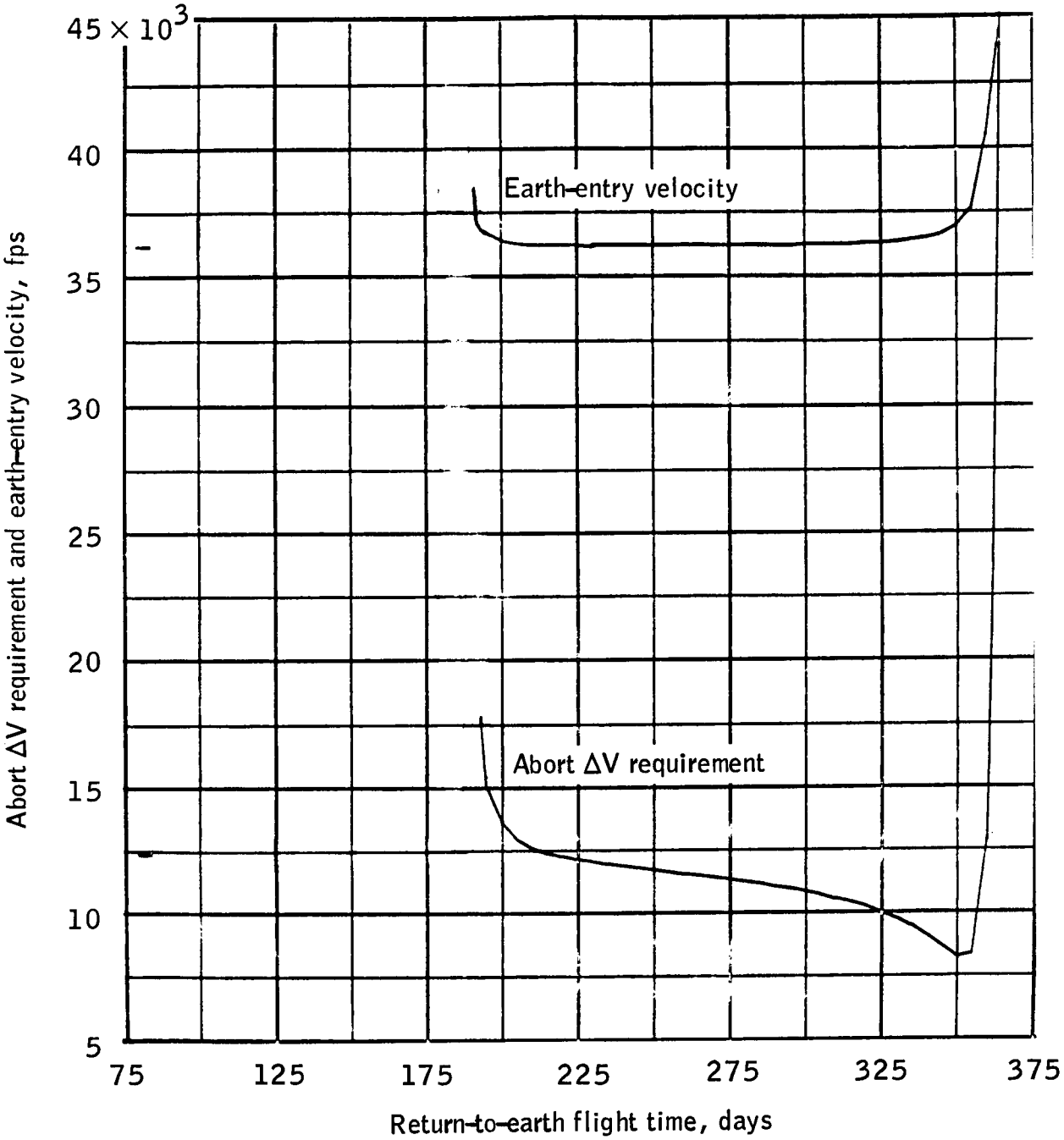

(a) Elapsed time to abort is 5 days after TMI.

Figure 9.- Velocity characteristics of heliocentric abort trajectories, 1986 Mars conjunction class mission.



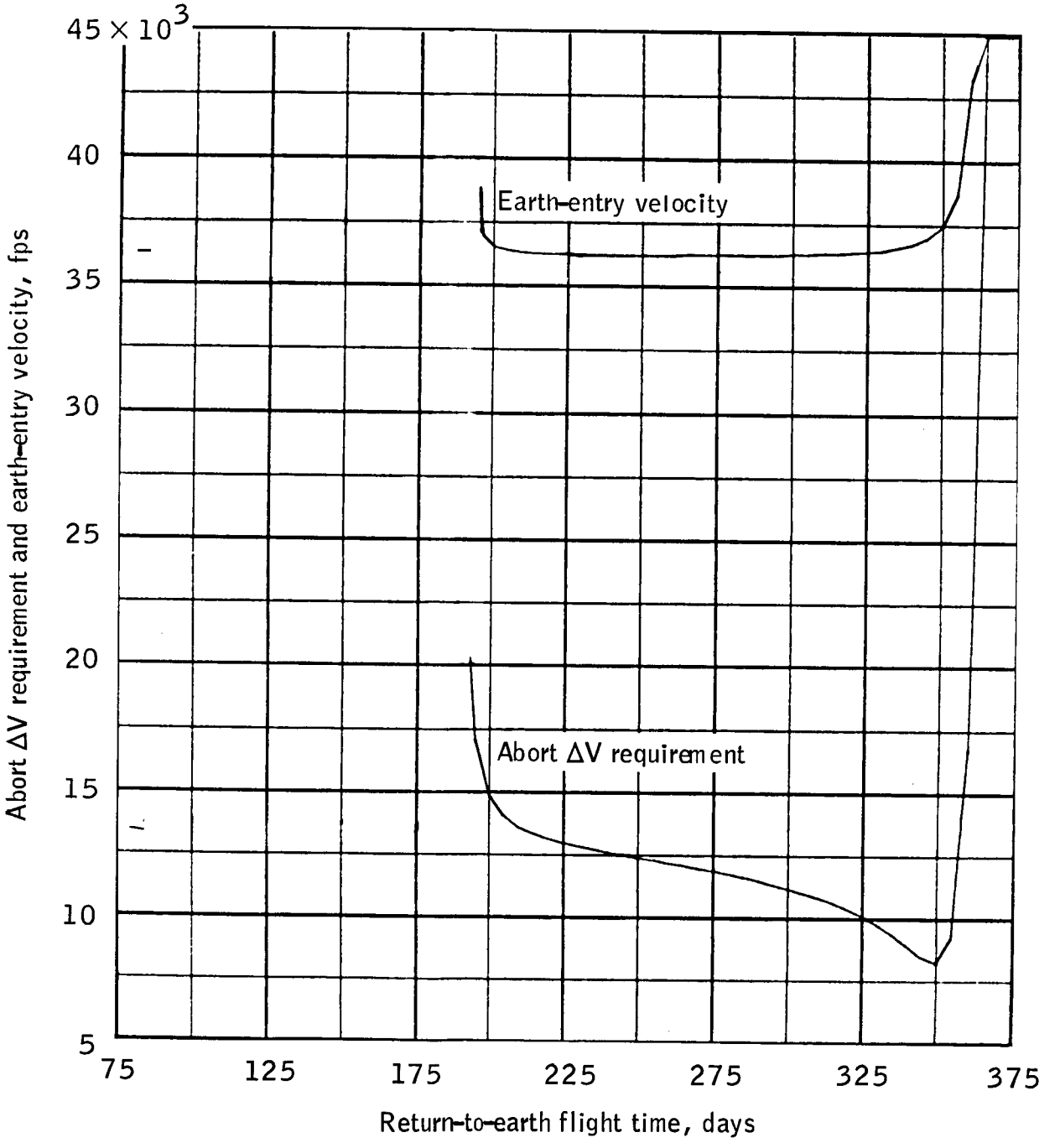

(b) Elapsed time to abort is 10 days after TMI.

Figure 9.- Continued.



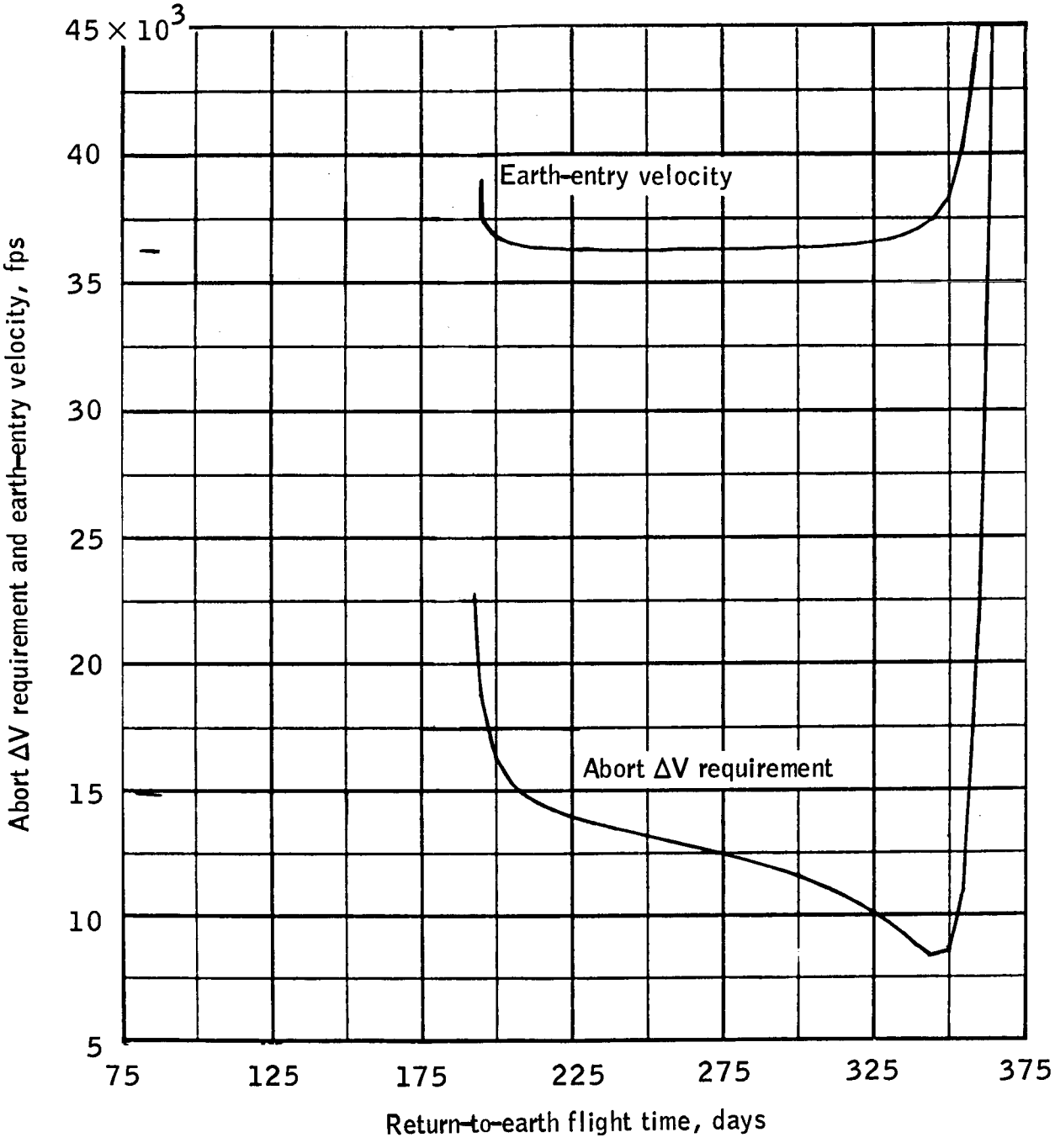

(c) Elapsed time to abort is 15 days after TMI.

Figure 9.- Continued.



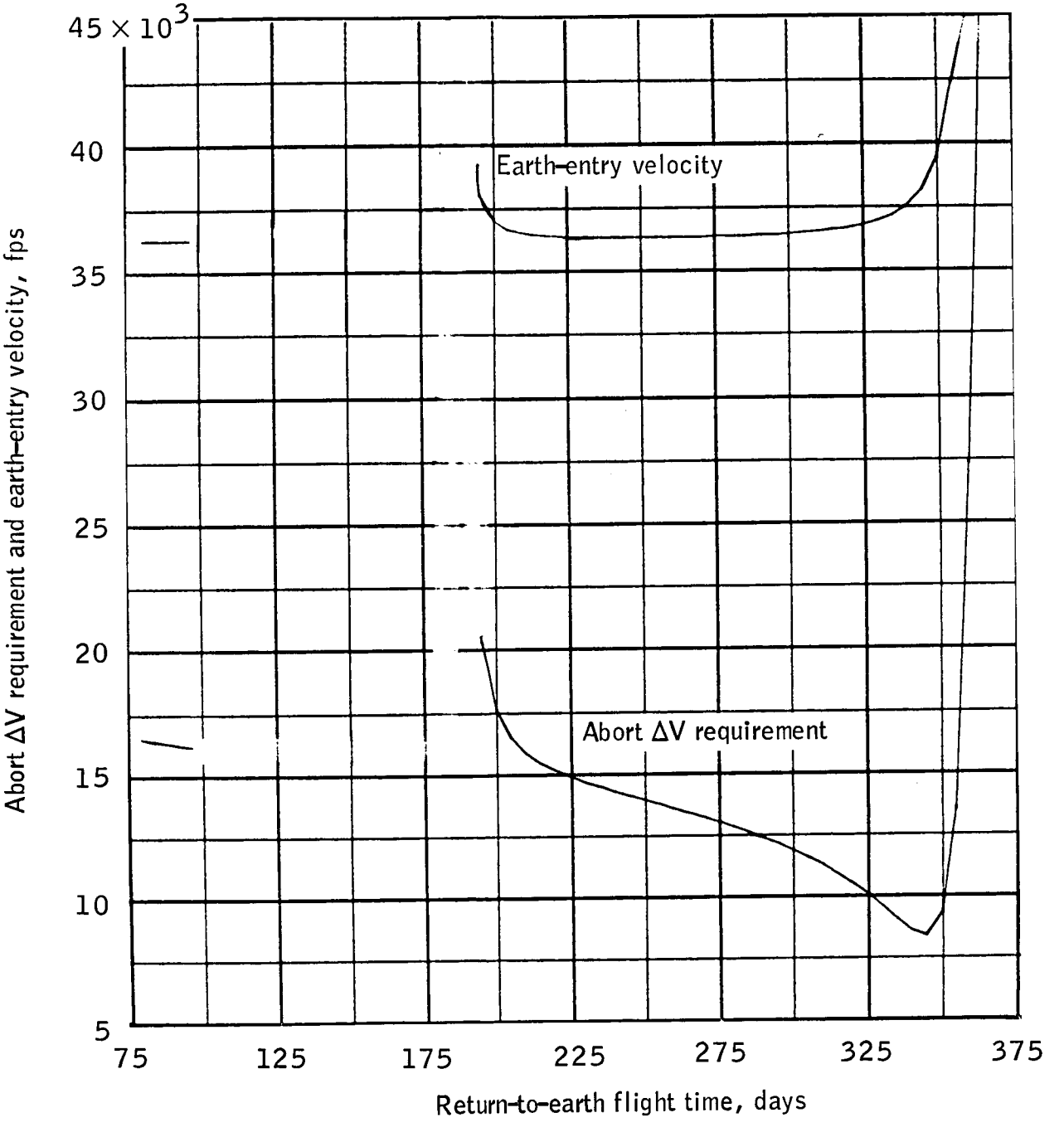

(d) Elapsed time to abort is 20 days after TMI.

Figure 9.- Continued.



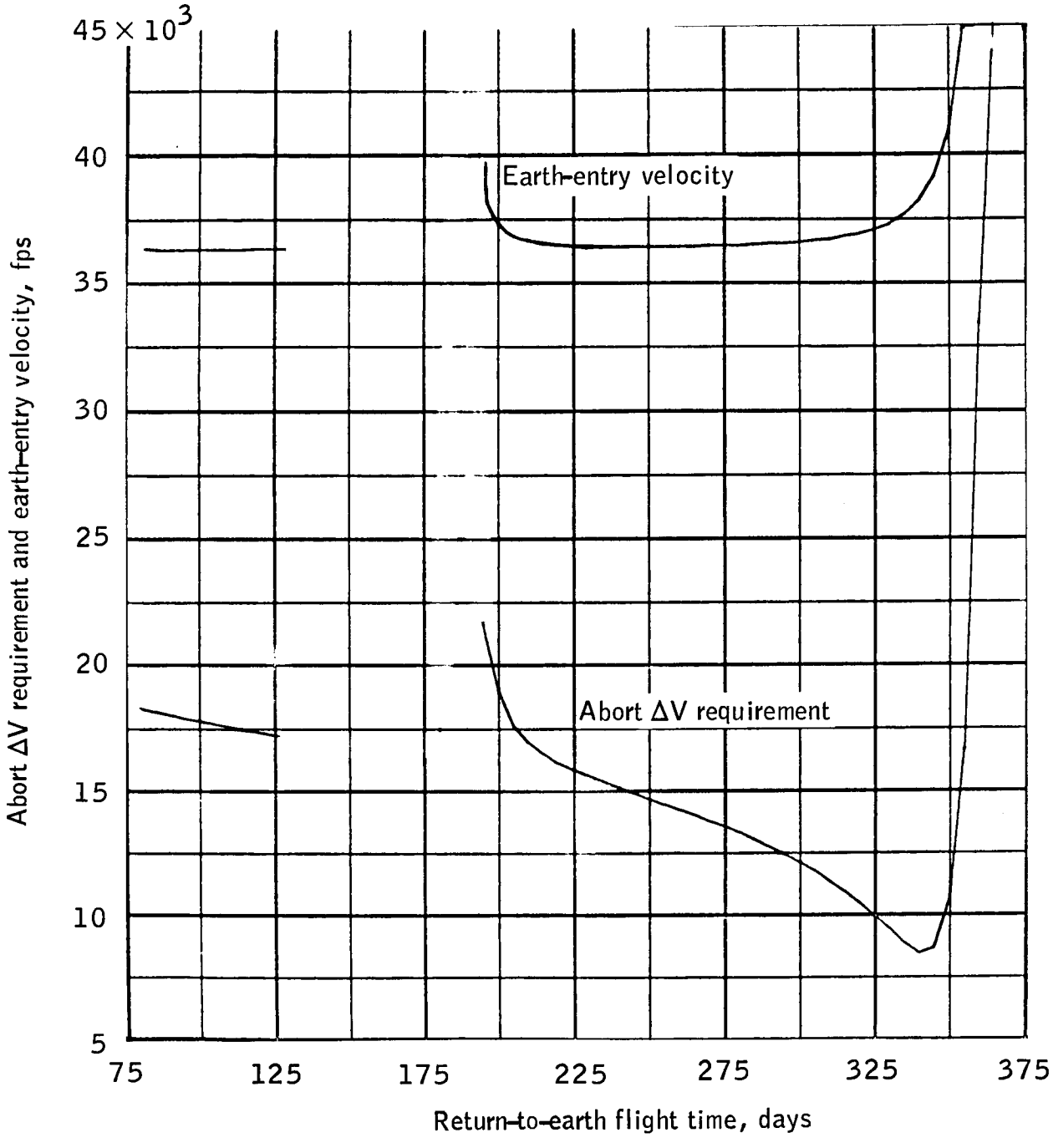

(e) Elapsed time to abort is 25 days after TMI.

Figure 9.- Continued.



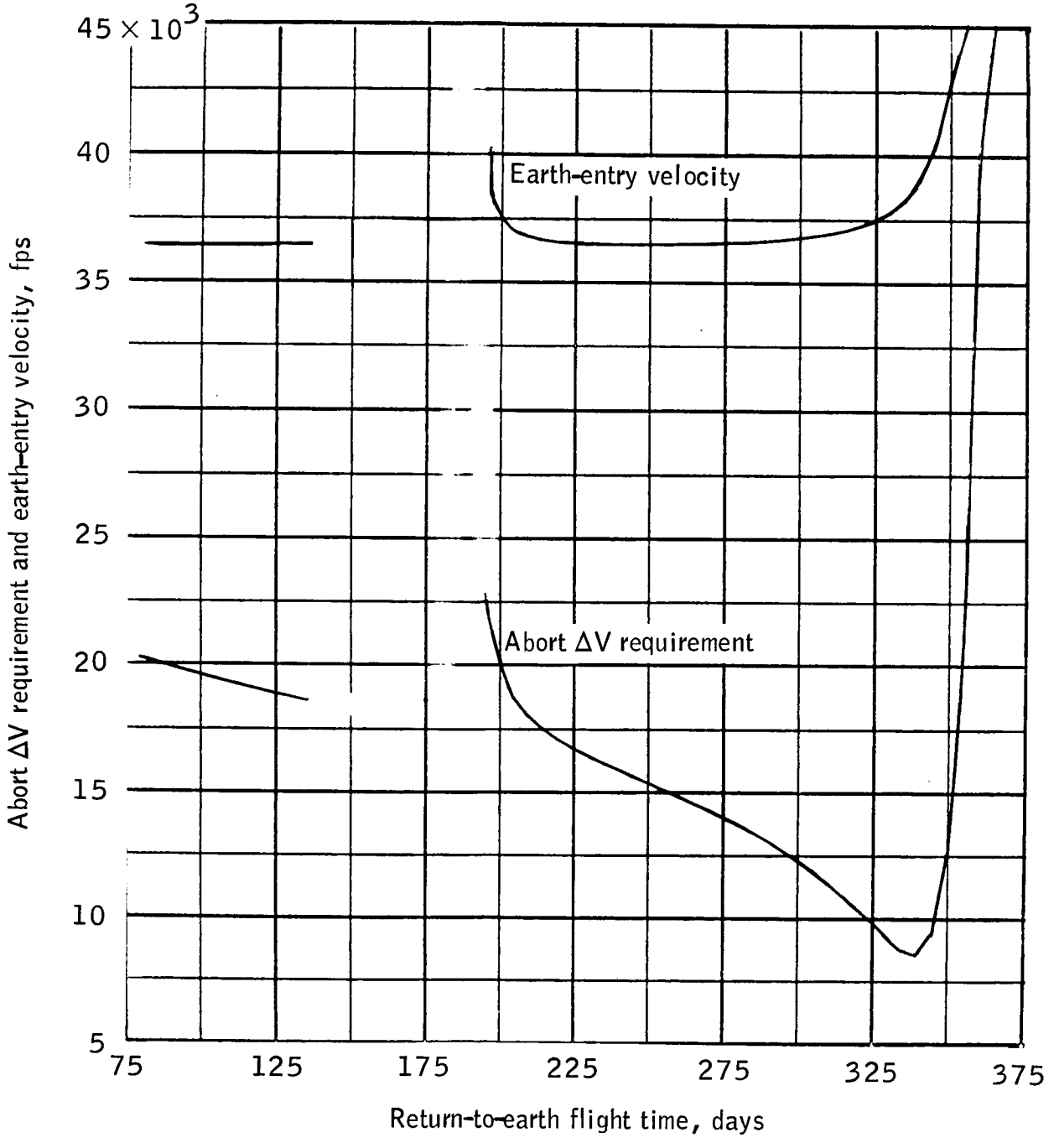

(f) Elapsed time to abort is 30 days after TMI.

Figure 9.- Continued.



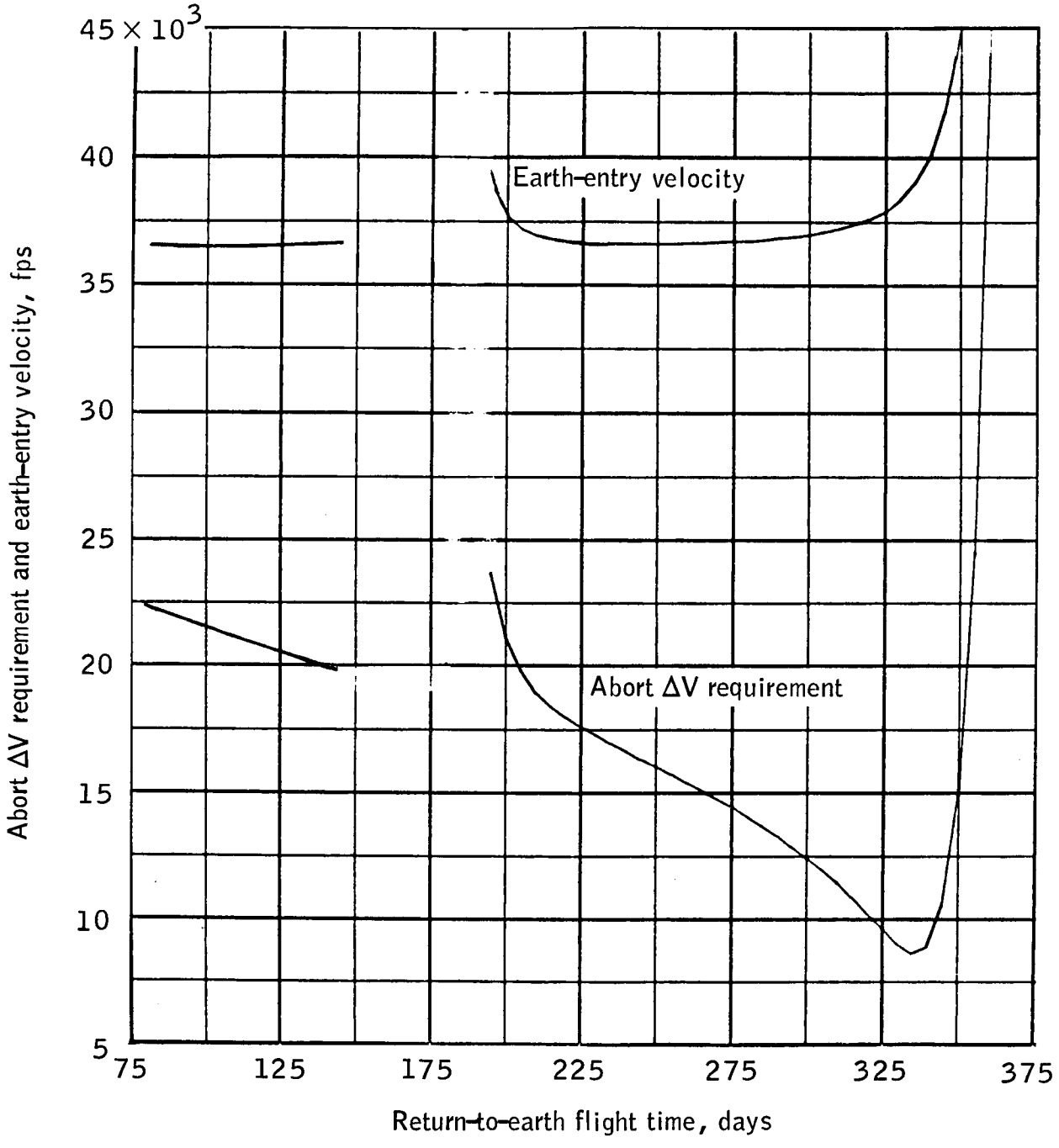

(g) Elapsed time to abort is 35 days after TMI.

Figure 9.- Continued.



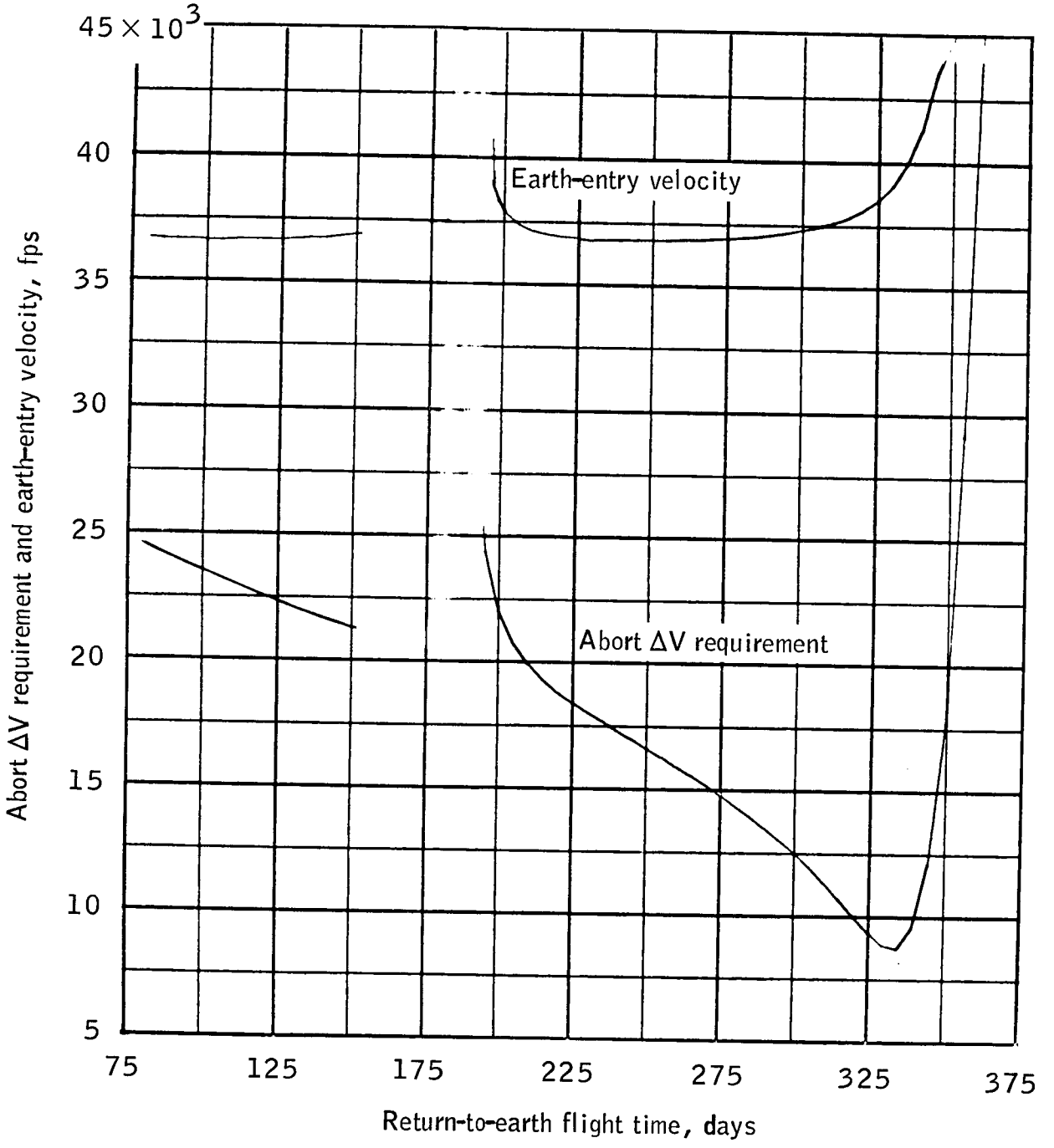

(h) Elapsed time to abort is 40 days after TMI.

Figure 9.- Continued.



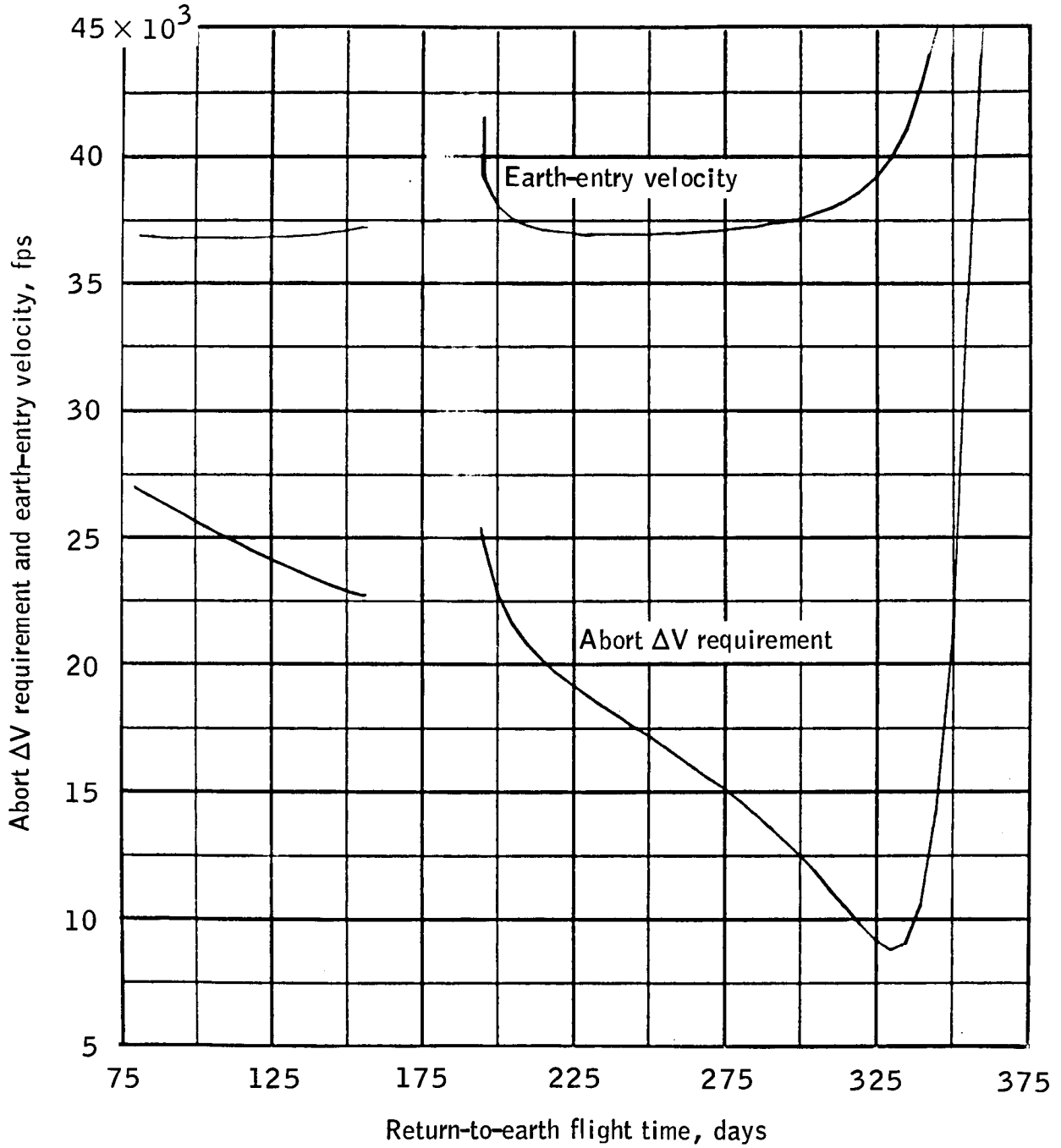

(i) Elapsed time to abort is 45 days after TMI.

Figure 9.- Continued.



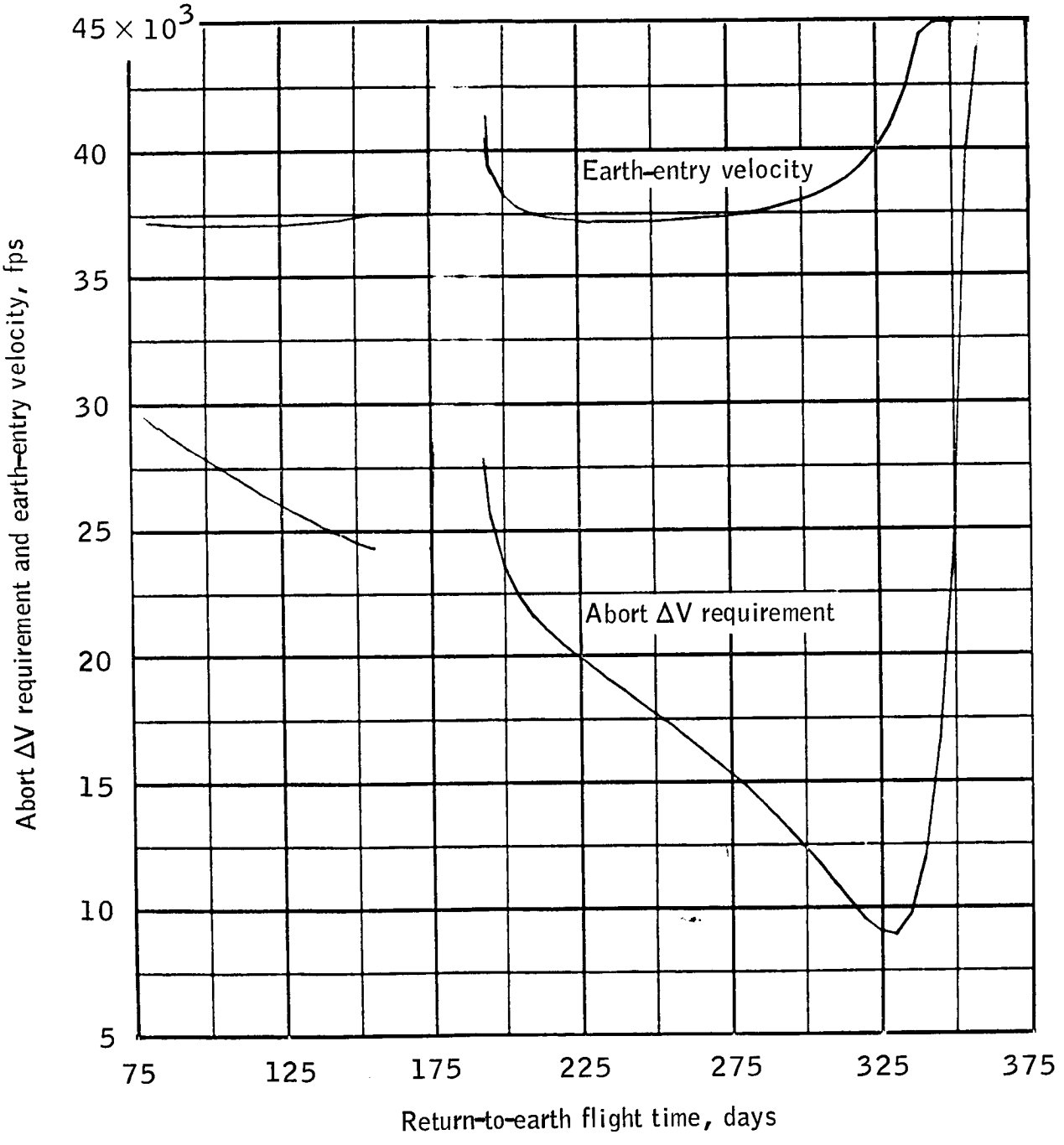

(j) Elapsed time to abort is 50 days after TMI.

Figure 9.- Continued.



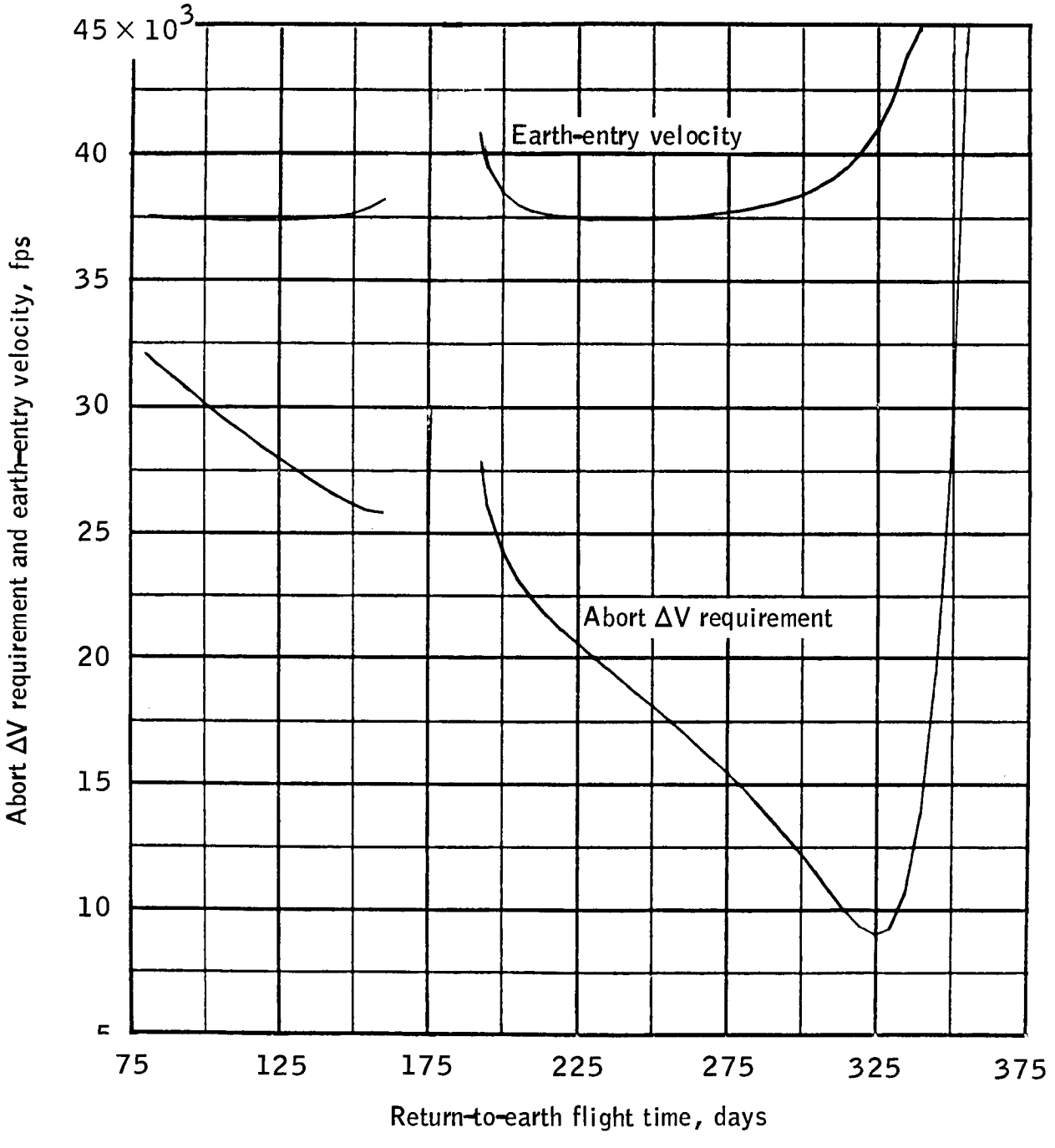

(k) Elapsed time to abort is 55 days after TMI.

Figure 9.- Continued.



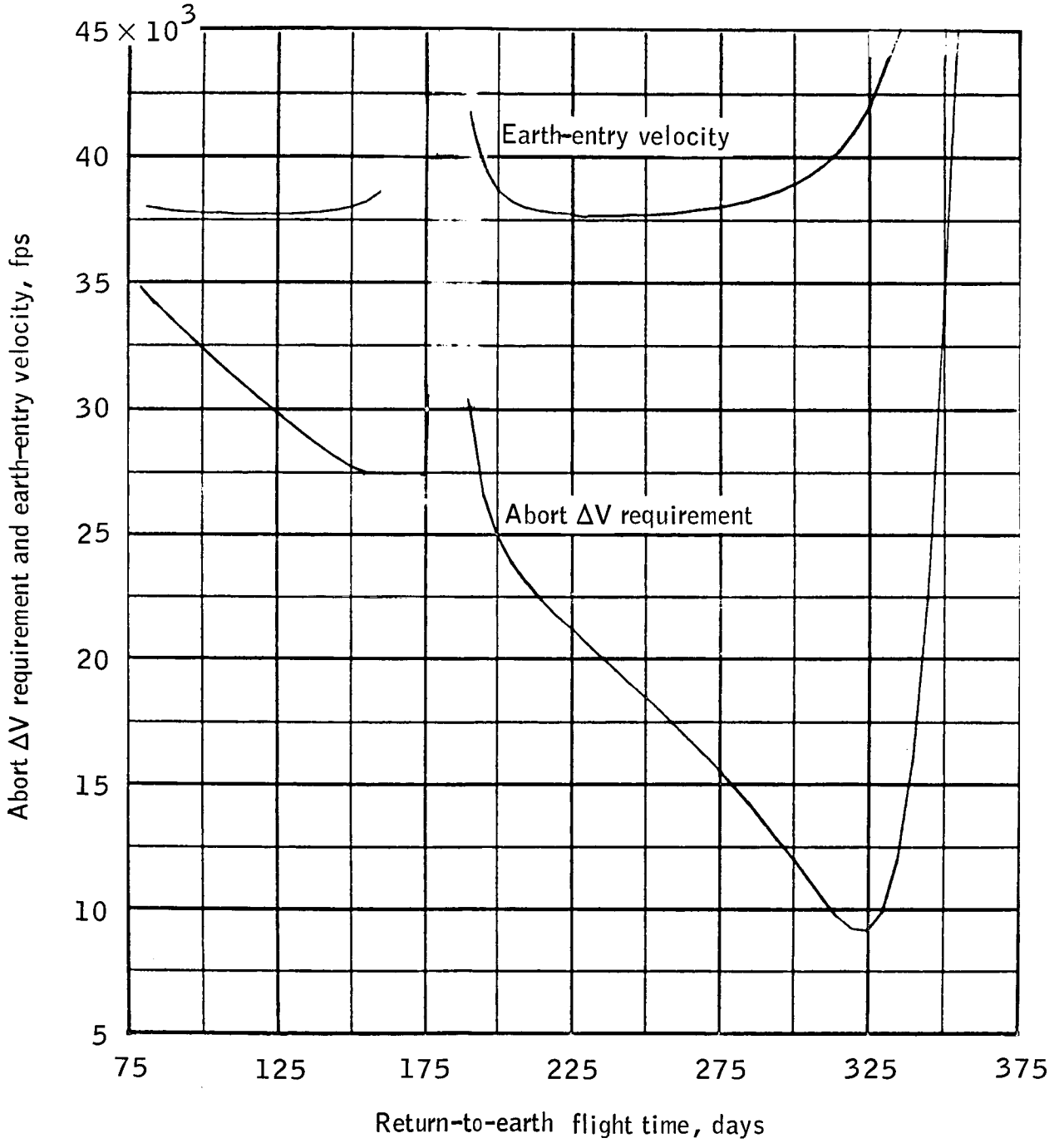

(l) Elapsed time to abort is 60 days after TMI.

Figure 9.- Continued.



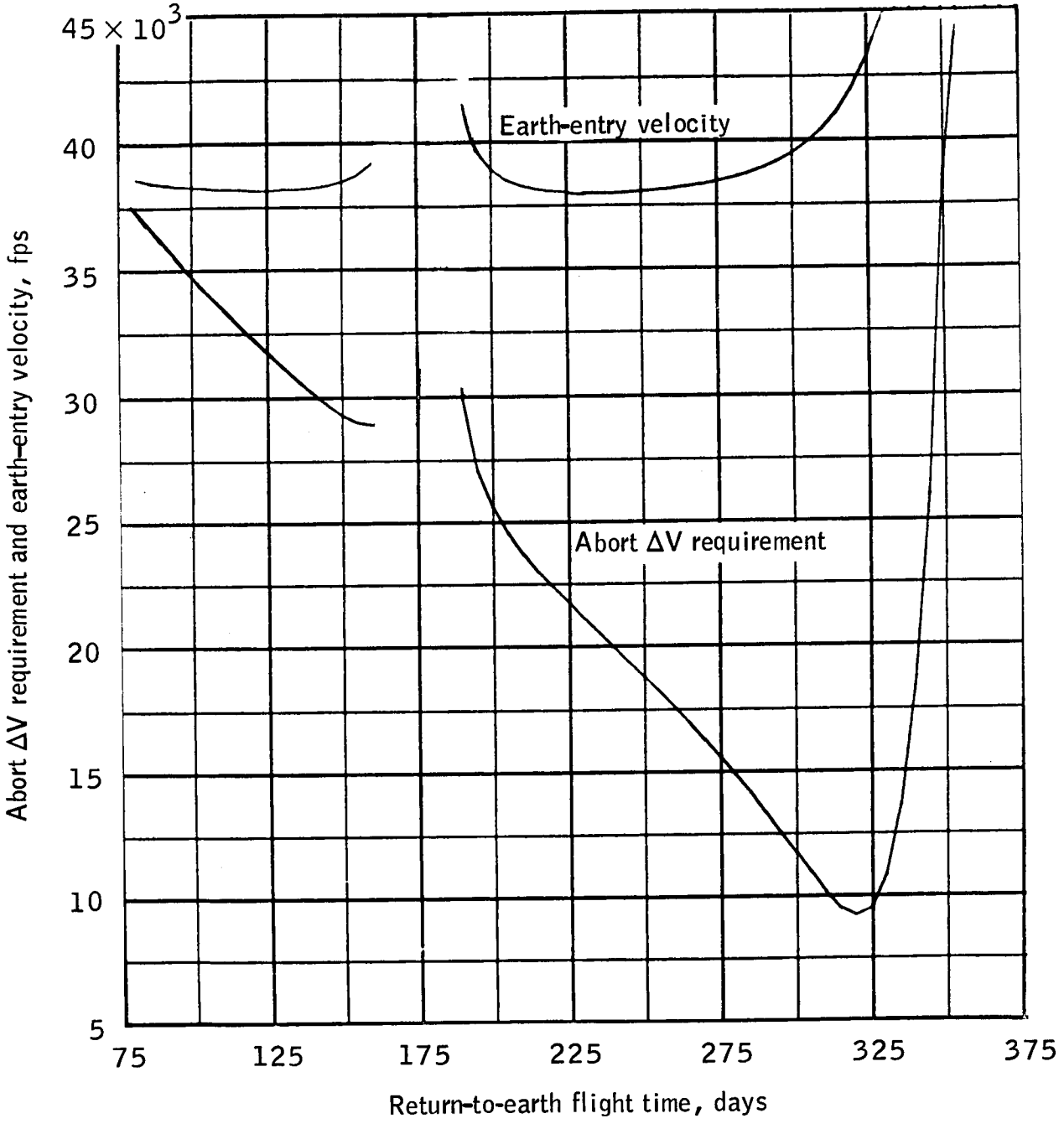

(m) Elapsed time to abort is 65 days after TMI.

Figure 9.- Continued.



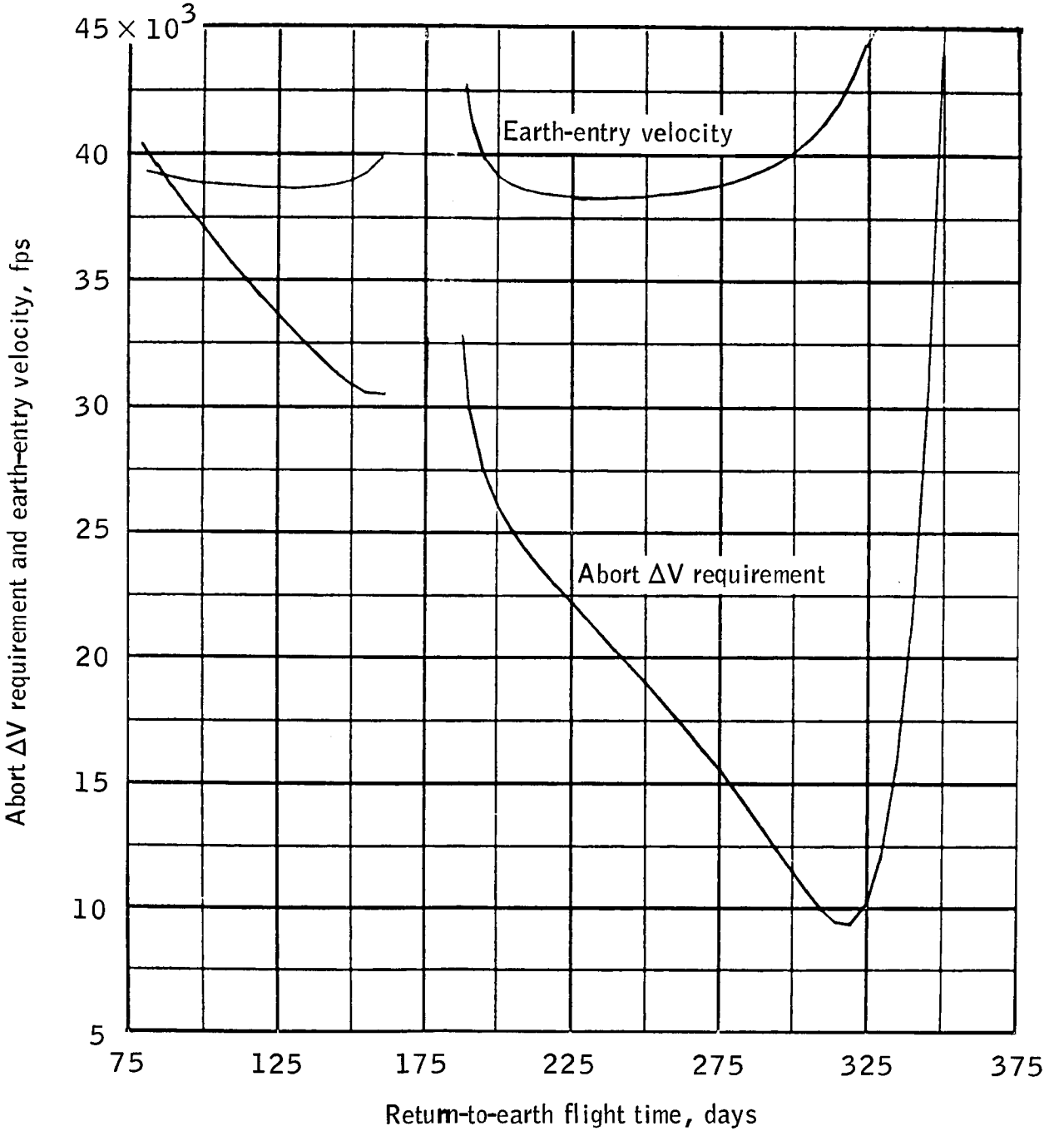

(n) Elapsed time to abort is 70 days after TMI.

Figure 9.- Continued.



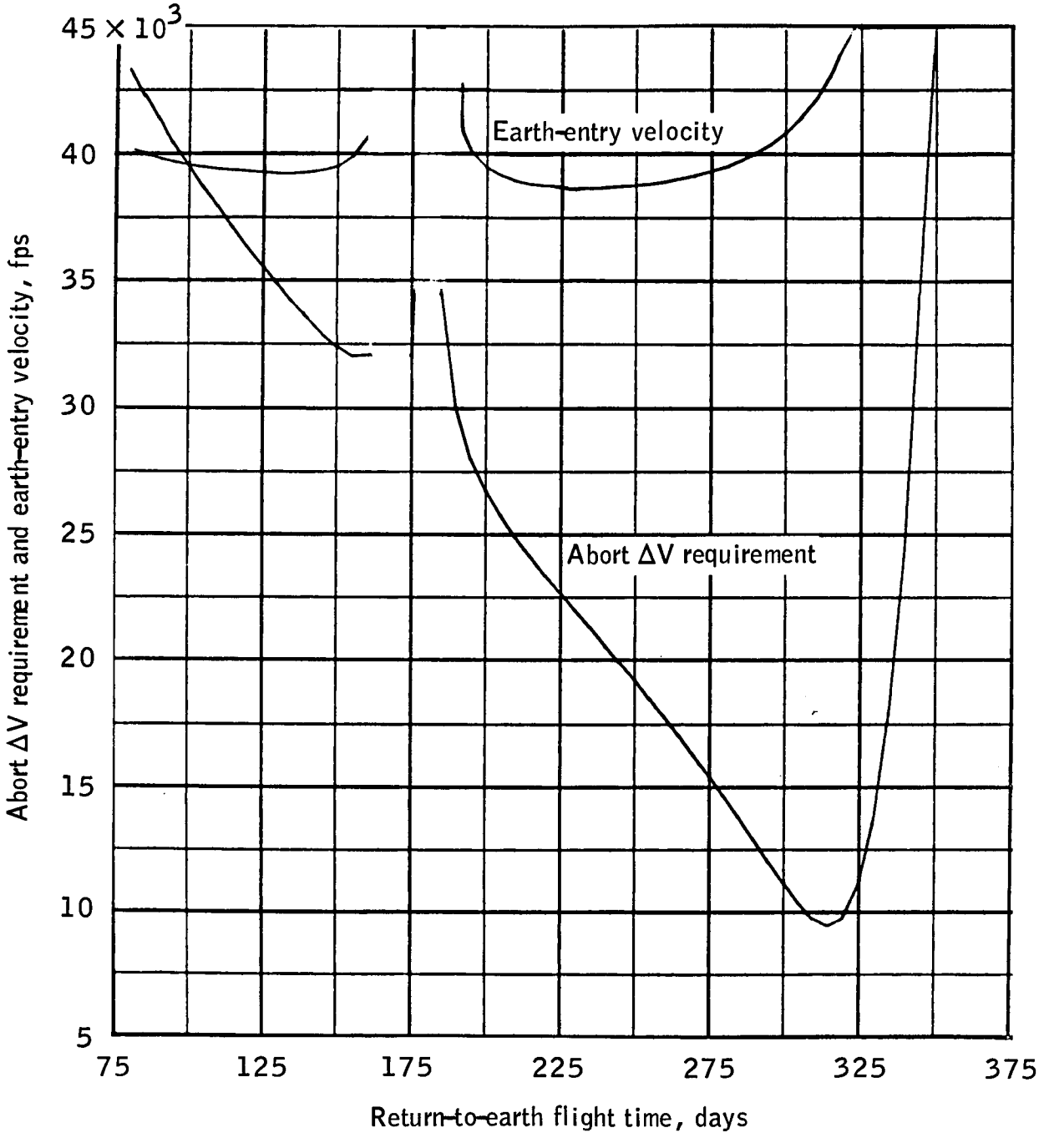

(o) Elapsed time to abort is 75 days after TMI.

Figure 9.- Continued.



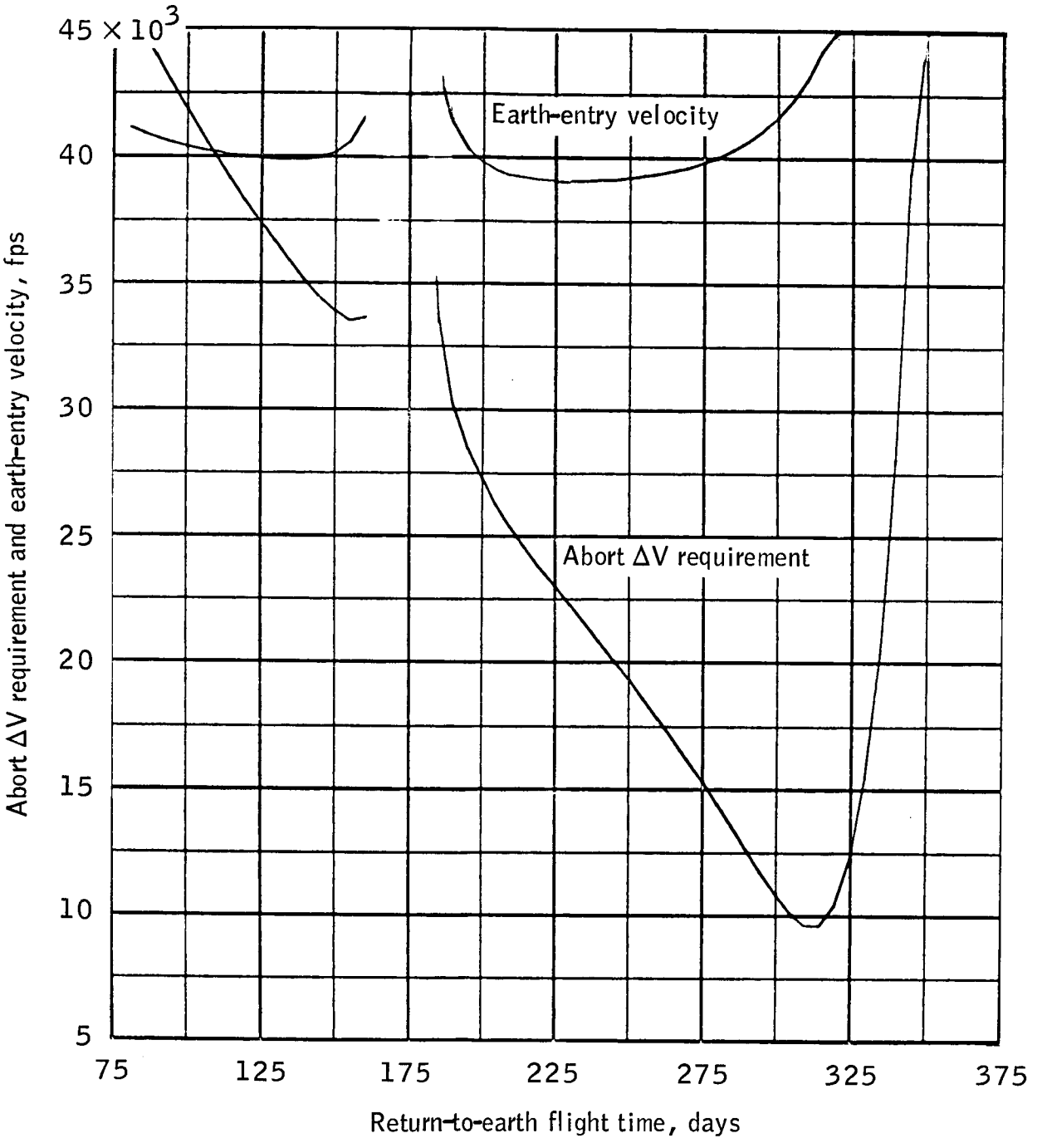

(p) Elapsed time to abort is 80 days after TMI.

Figure 9.- Continued.



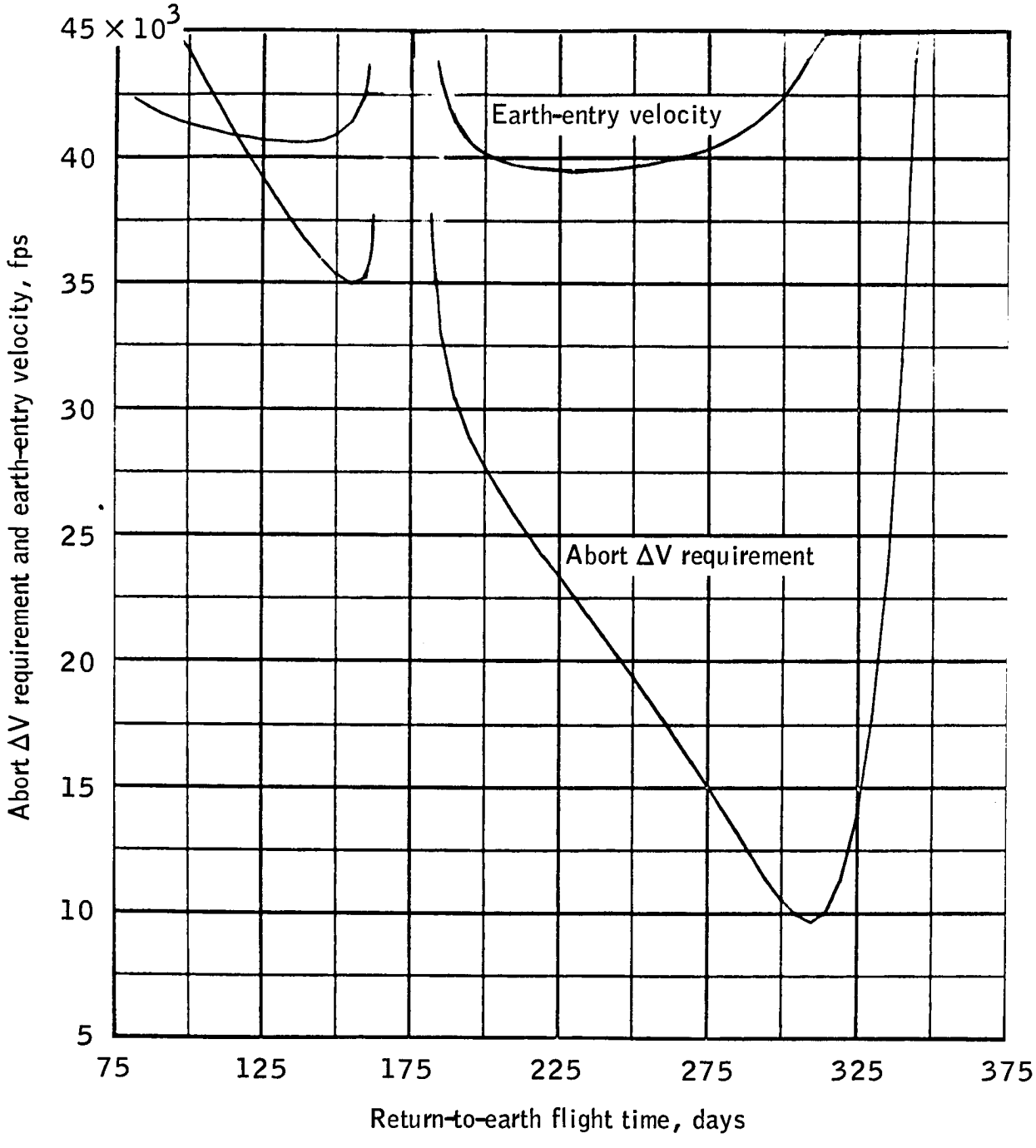

(q) Elapsed time to abort is 85 days after TMI.

Figure 9.- Continued.



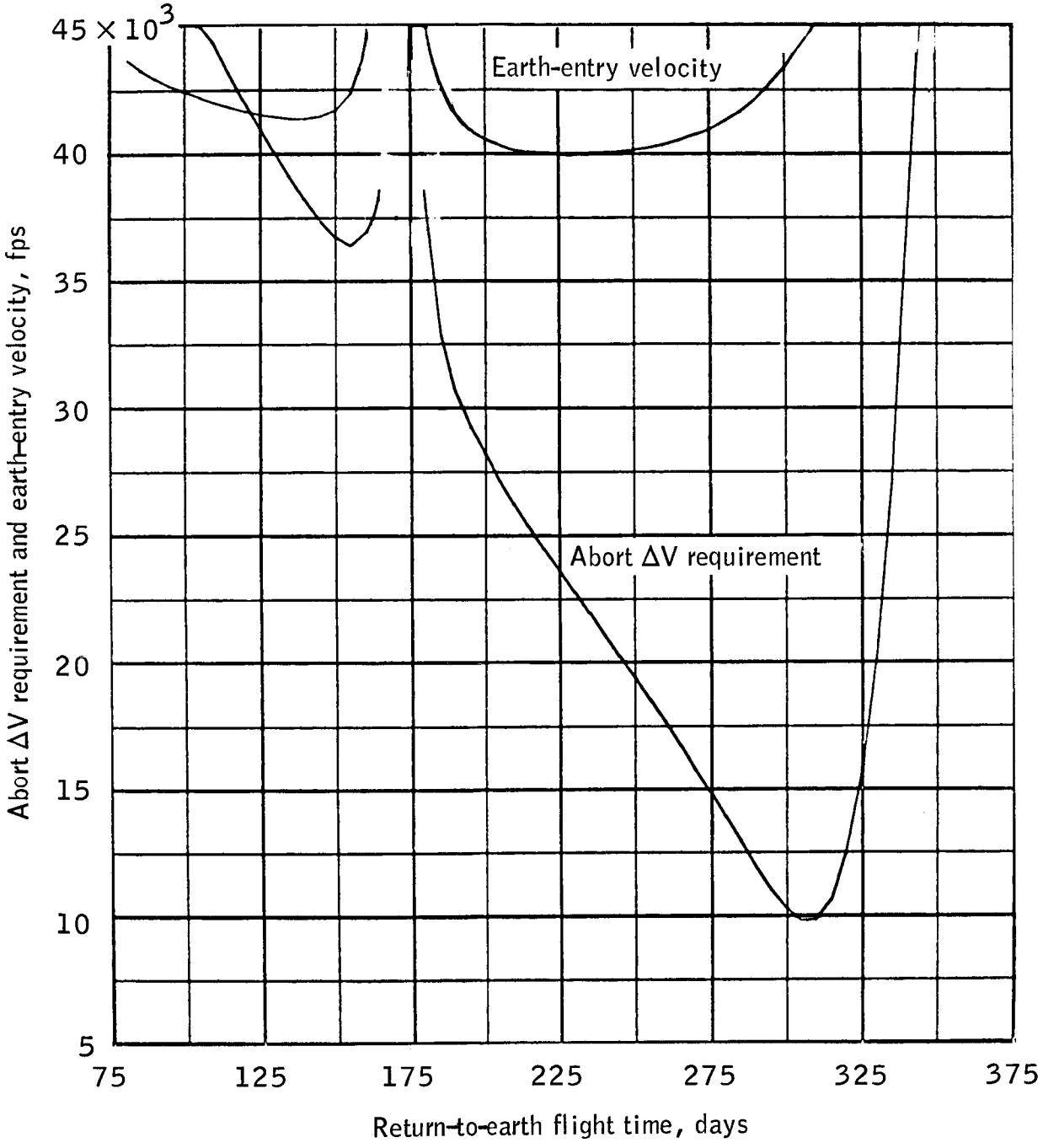

(r) Elapsed time to abort is 90 days after TMI.

Figure 9.- Continued.



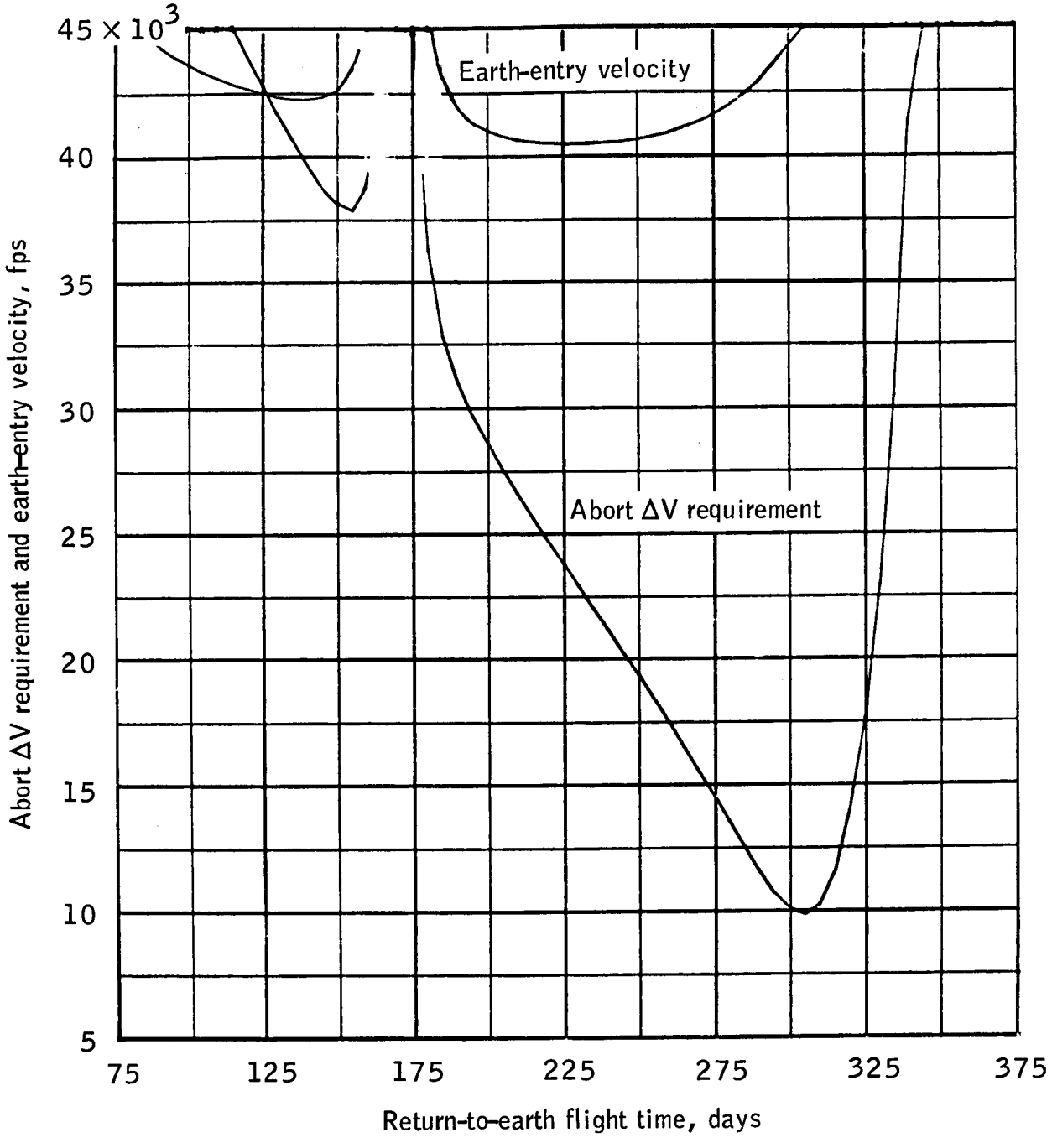

(s) Elapsed time to abort is 95 days after TMI.

Figure 9.- Continued.



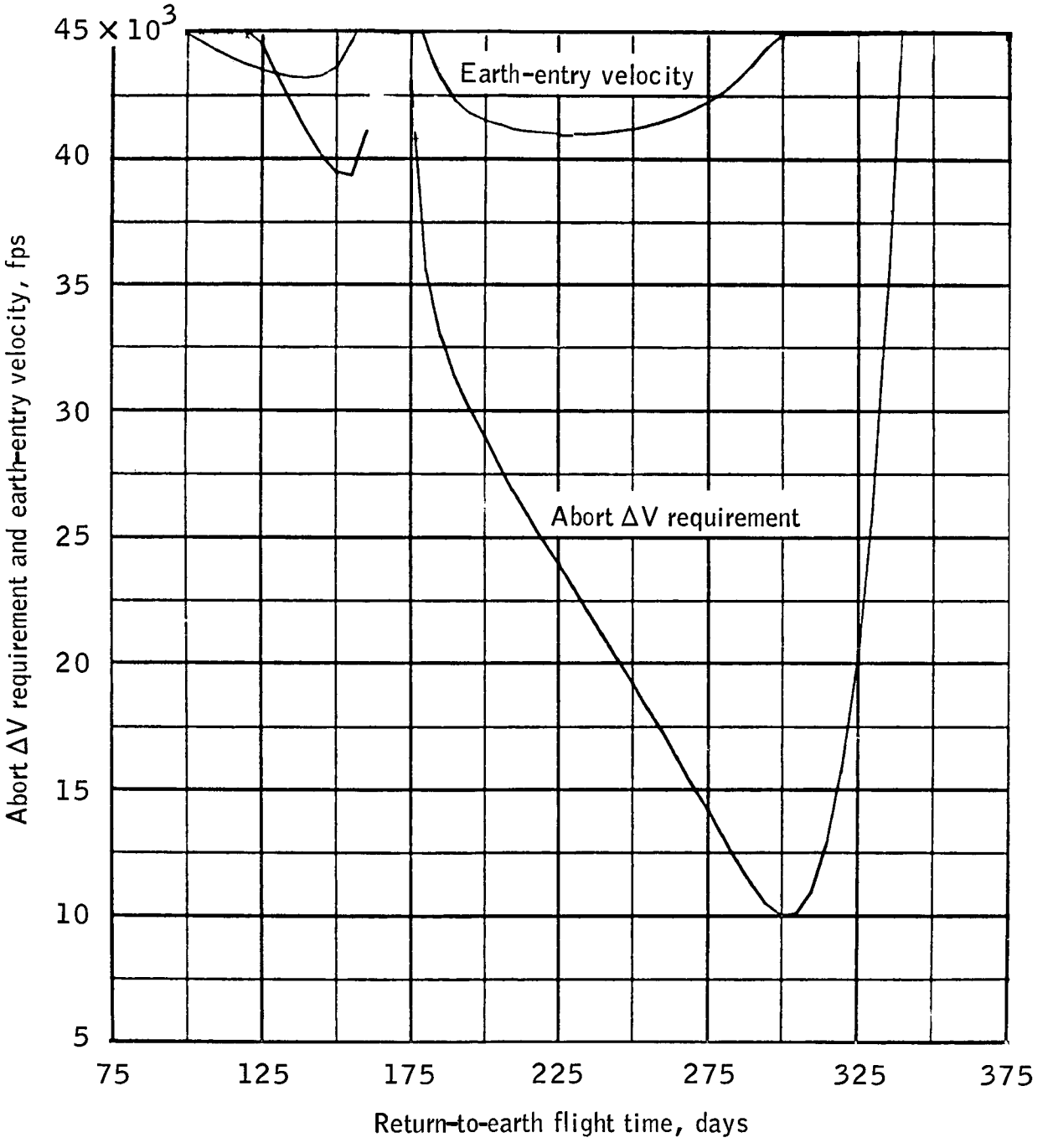

(t) Elapsed time to abort is 100 days after TMI.

Figure 9.- Continued.



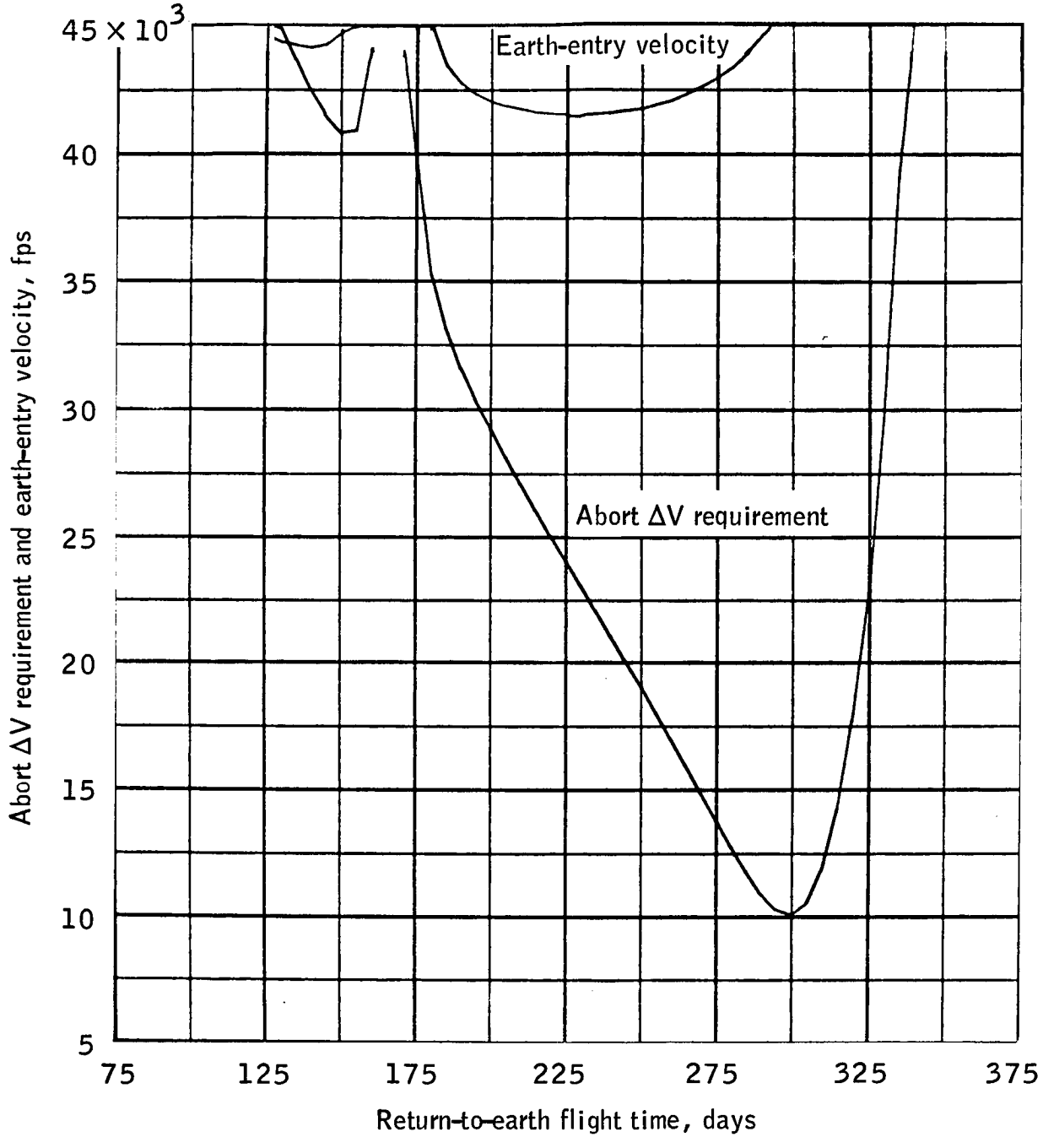

(u) Elapsed time to abort is 105 days after TMI.

Figure 9.- Continued.



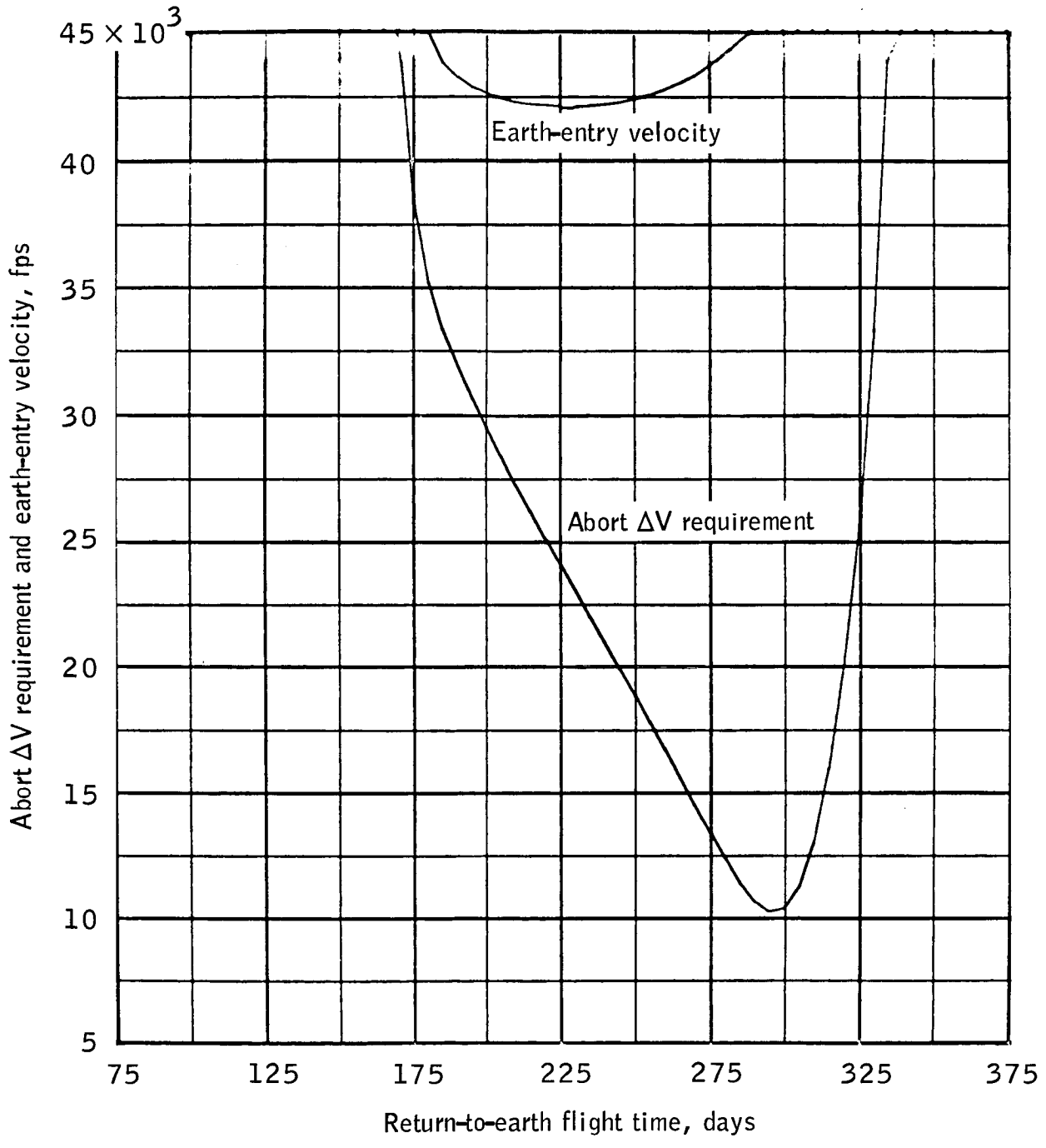

(v) Elapsed time to abort is 110 days after TMI.

Figure 9.- Continued.



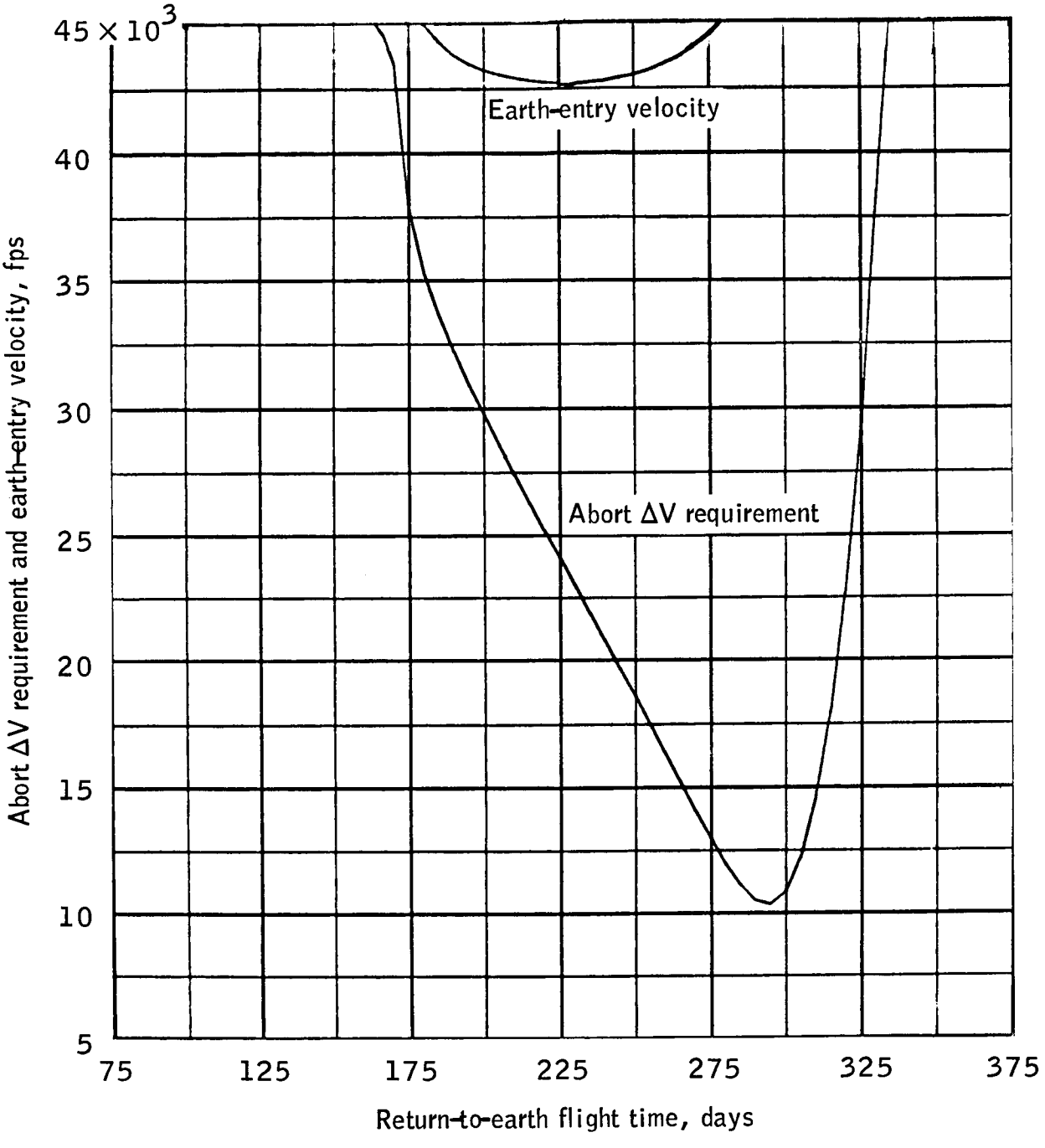

(w) Elapsed time to abort is 115 days after TMI.

Figure 9.- Continued.



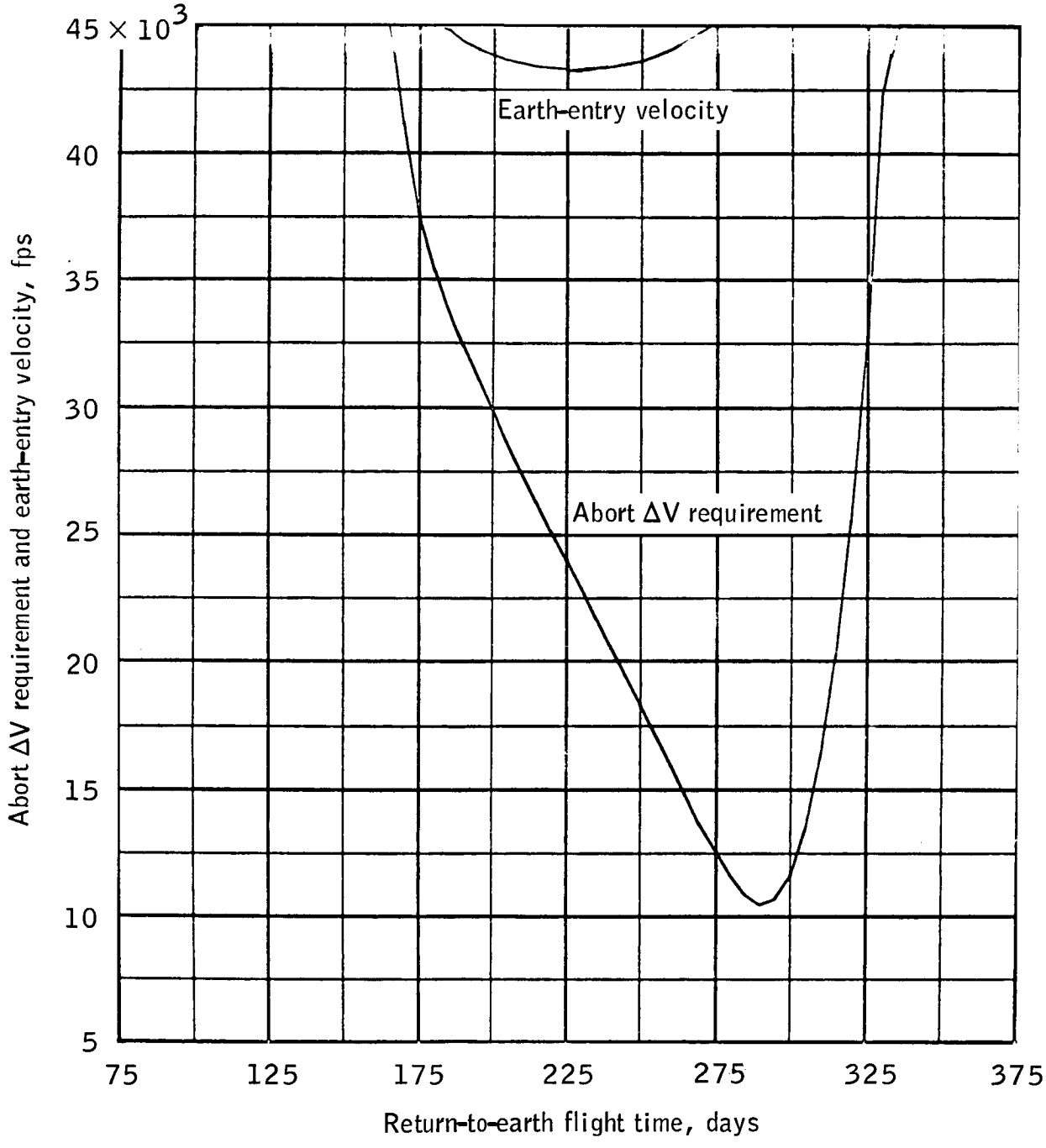

(x) Elapsed time to abort is 120 days after TMI.

Figure 9.- Continued.



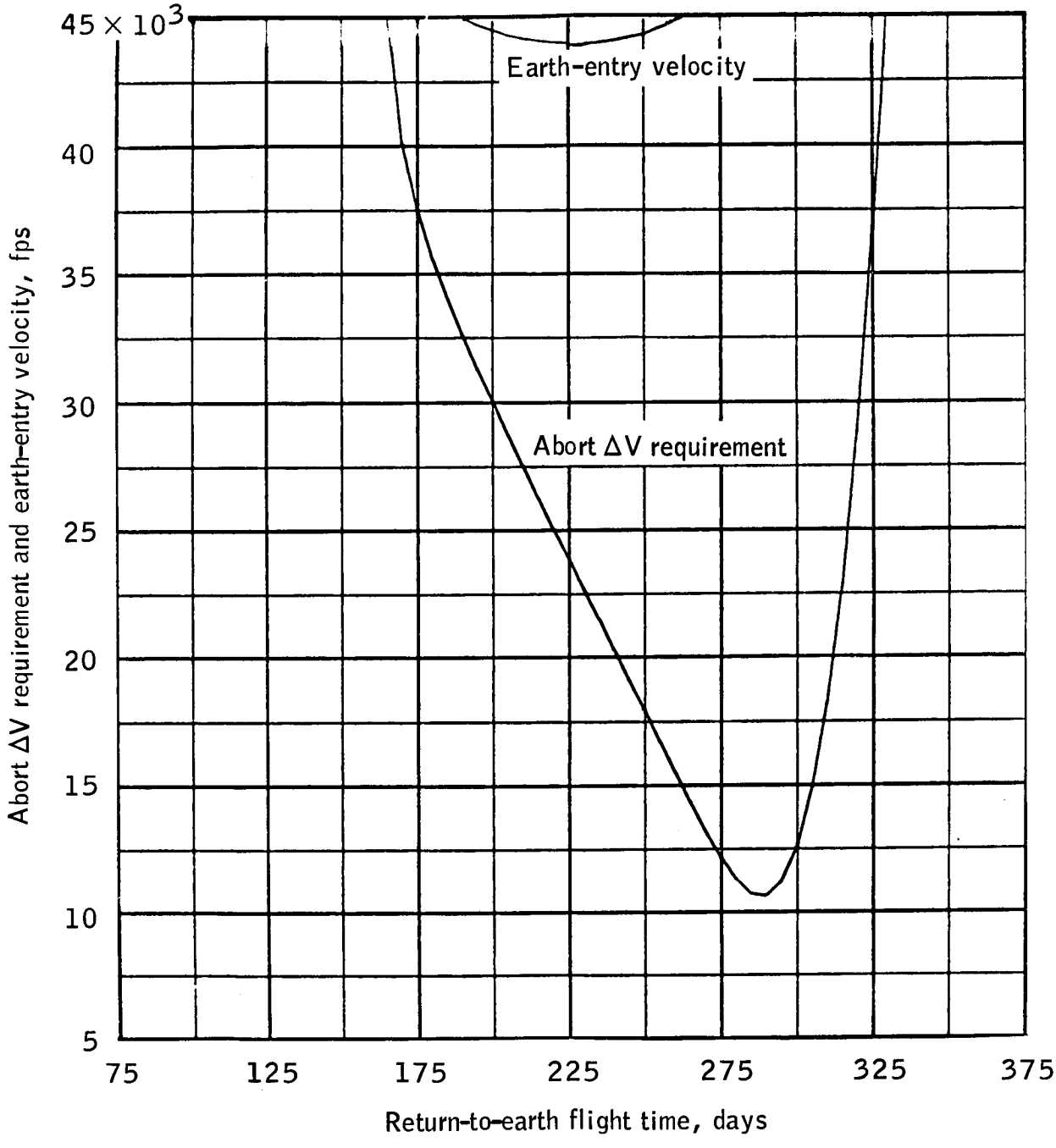

(y) Elapsed time to abort is 125 days after TMI.

Figure 9.- Continued.



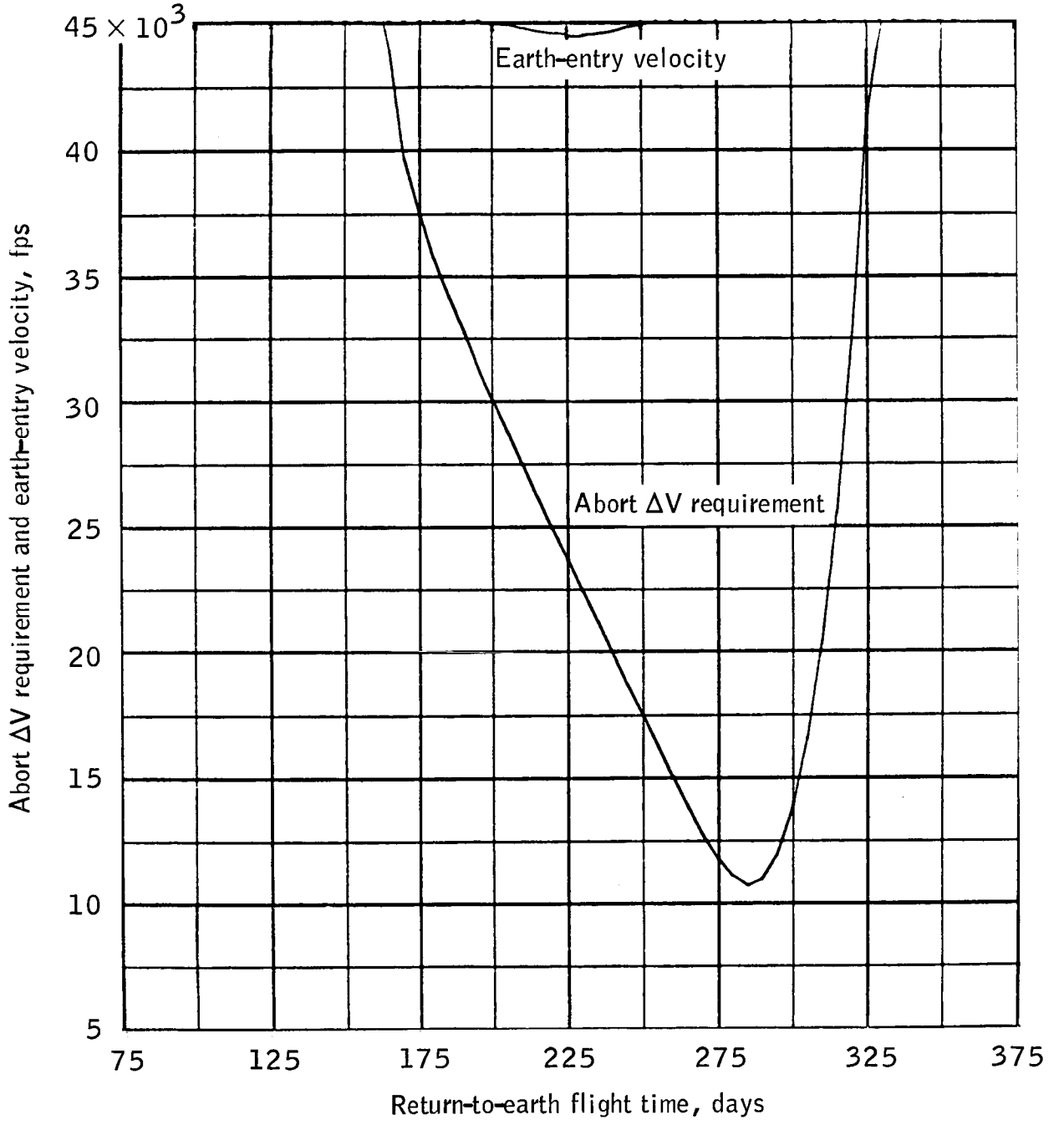

(z) Elapsed time to abort is 130 days after TMI.

Figure 9.- Continued.



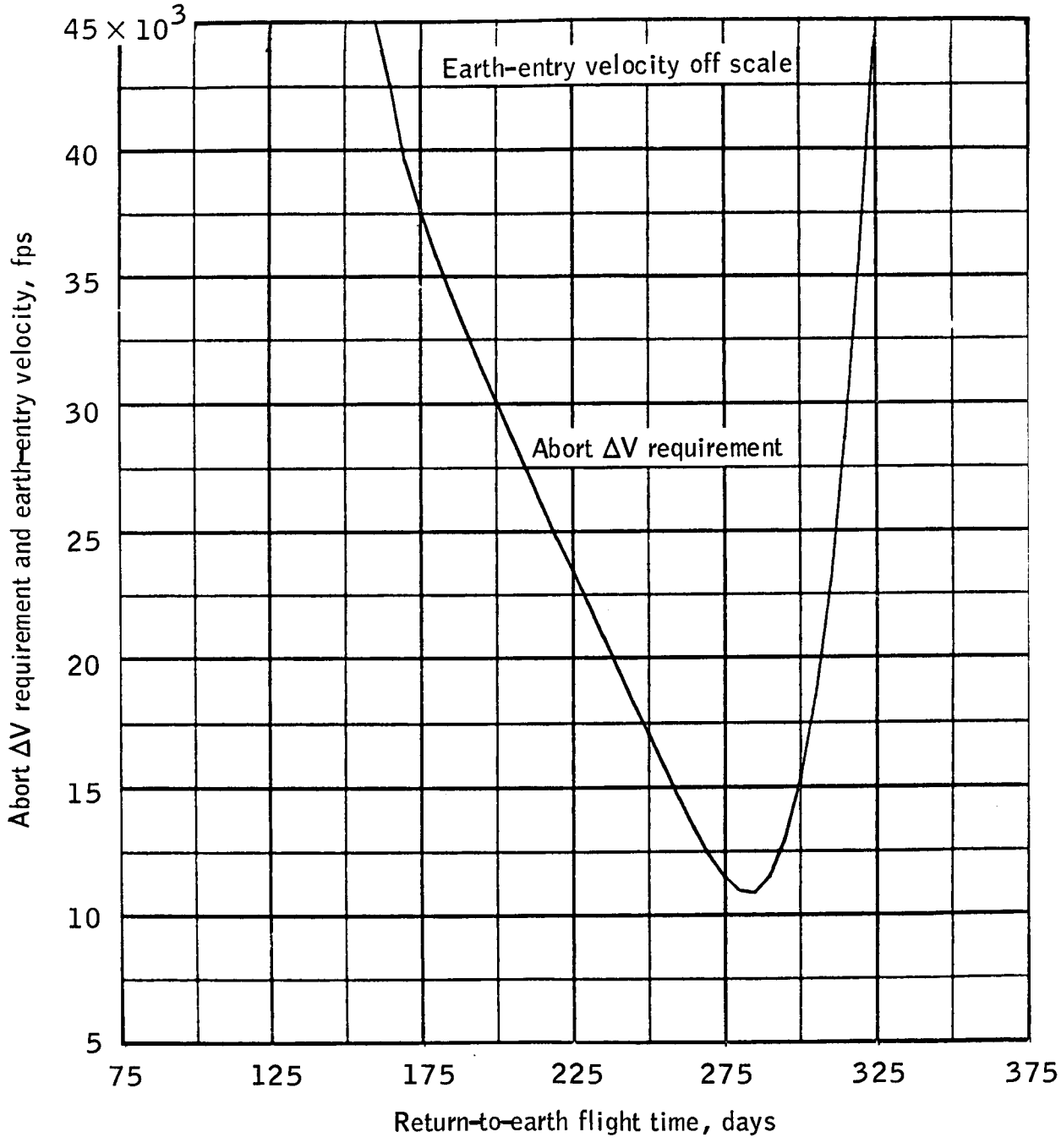

(aa) Elapsed time to abort is 135 days after TMI.

Figure 9.- Continued.



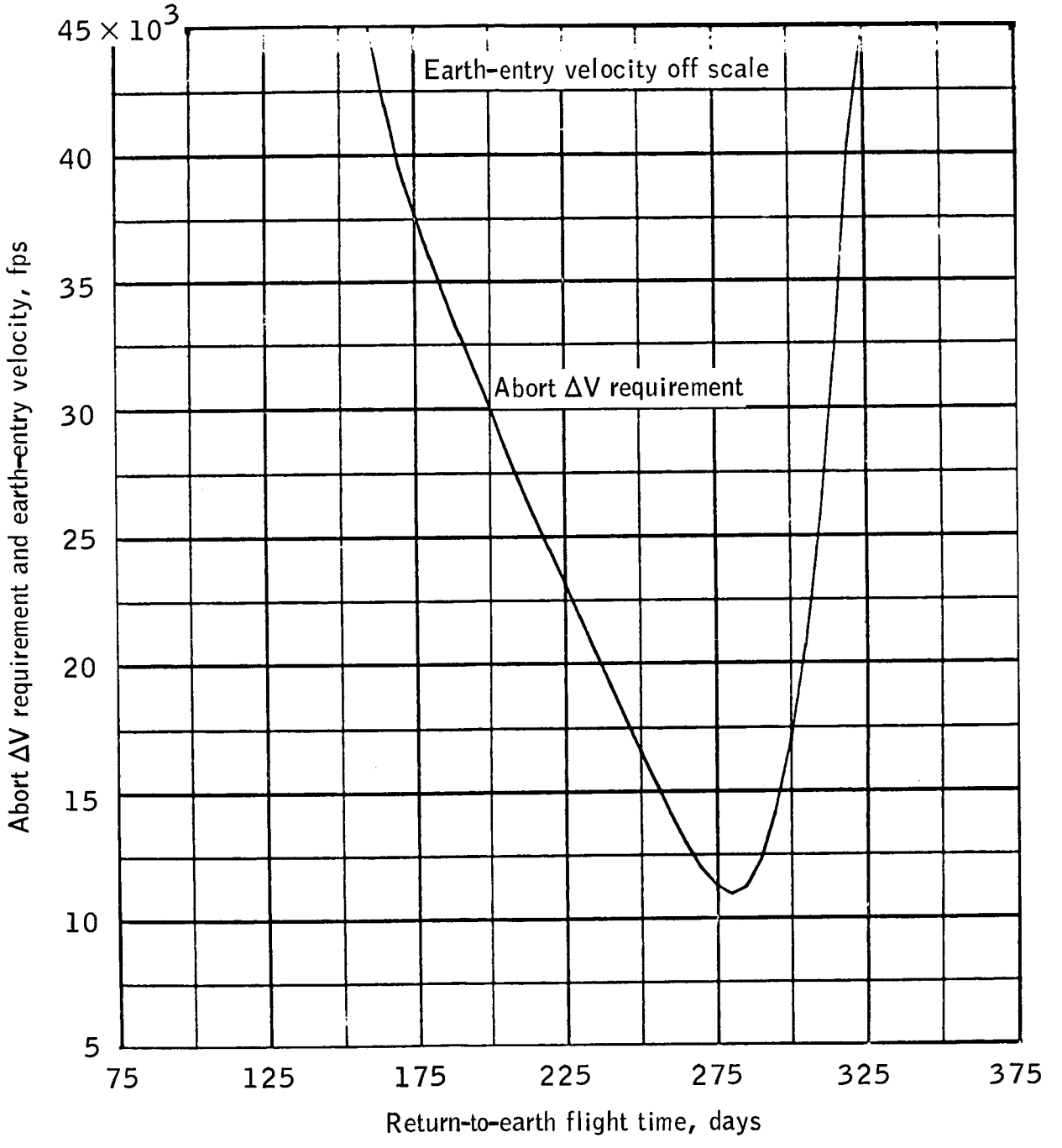

(bb) Elapsed time to abort is 140 days after TMI.

Figure 9.- Continued.




(cc) Elapsed time to abort is 145 days after TMI.

Figure 9.- Continued.




(dd) Elapsed time to abort is 150 days after TMI.

Figure 9.- Concluded.

## REFERENCE

1. Funk, Jack; Taylor, James J.; Thibodeau, J. R., III; Lowes, Flora B.; and McNeely, John T.: Manned Exploration of Mars: A Minimum-Energy Mission Plan for Maximum Scientific Return. MSC IN 68-FM-70, April 1, 1968.